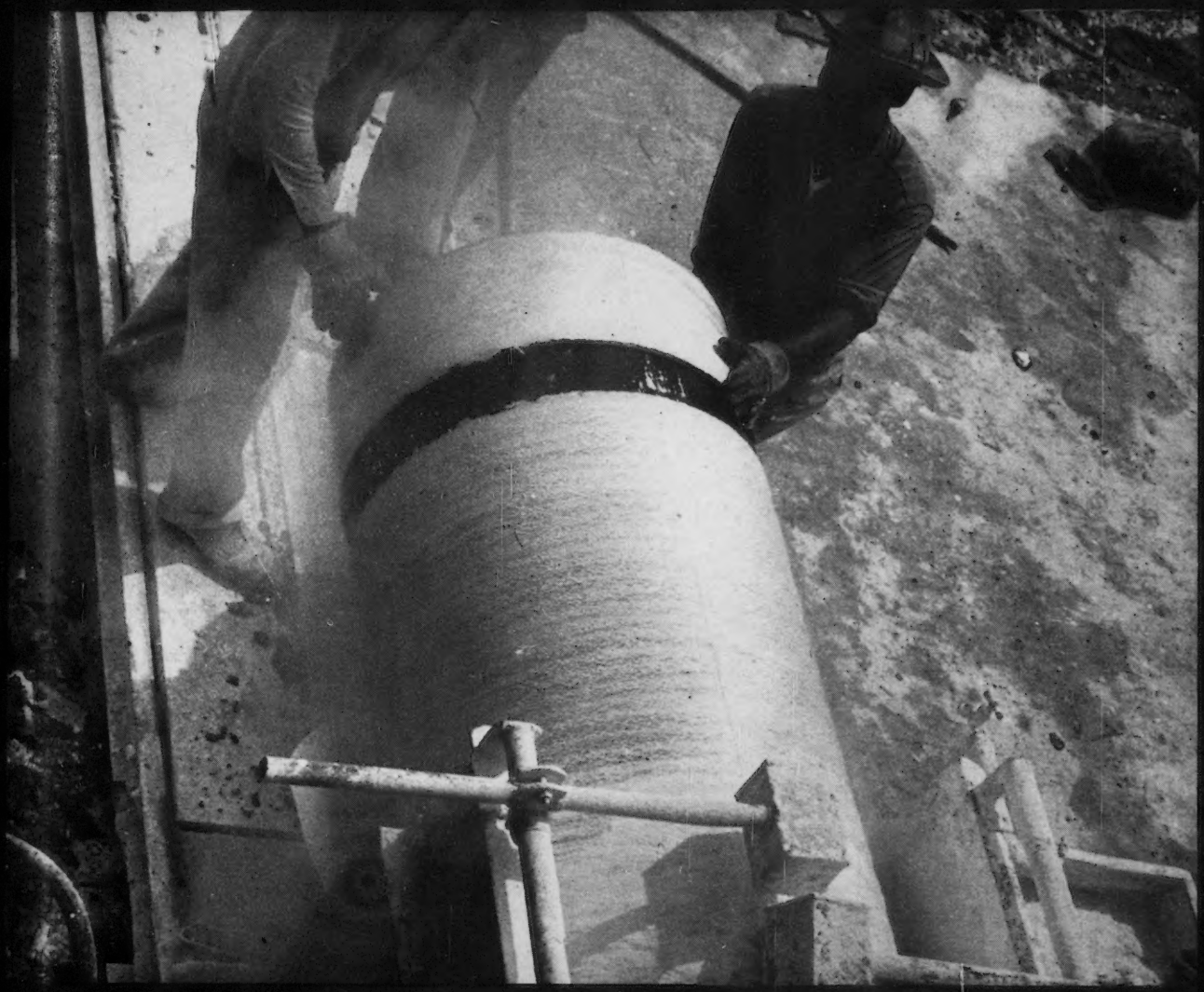
# Corrosion

Official Publication of
NATIONAL ASSOCIATION OF CORROSION ENGINEERS



JULY 1951 No. 7

# CORROSION CRIPPLES-MORE WAYS THAN ONE

## *Valuable products as well as vital equipment are threatened*

Corrosion takes its toll in more ways than one—it eats away costly, hard-to-get equipment—wastes man-hours while plants are shut down for repairs—and causes loss of vitally-needed products through contamination.

Every industry suffers from corrosion in some form, yet much of this waste can be avoided by taking these steps:

1. Check manufacturing equipment, storage tanks, and other items exposed to corrosive fumes, acids, alkalies, or moisture.
2. Arrange to protect them with AMERCOAT — the corrosion resistant coatings, each built to conquer specific industrial corrosion problems.

Manufacturers in nearly every industry have found that it pays to protect — protect with AMERCOAT.

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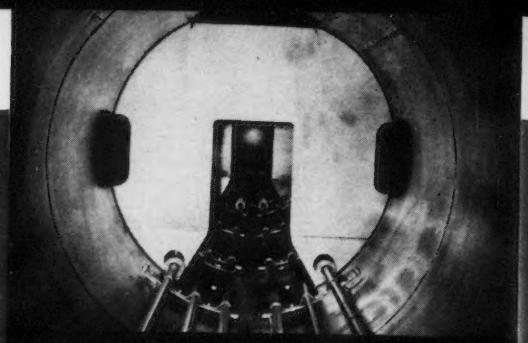
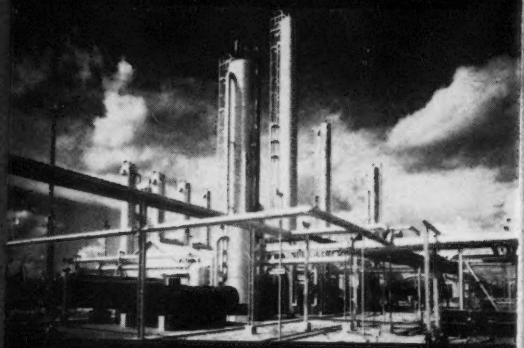
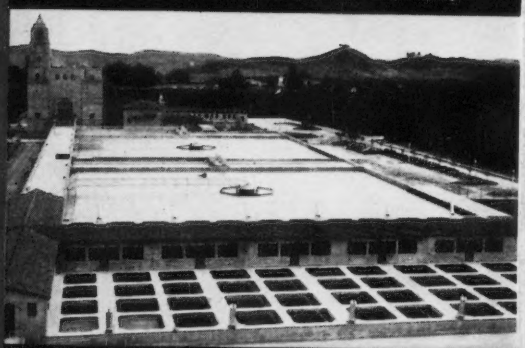


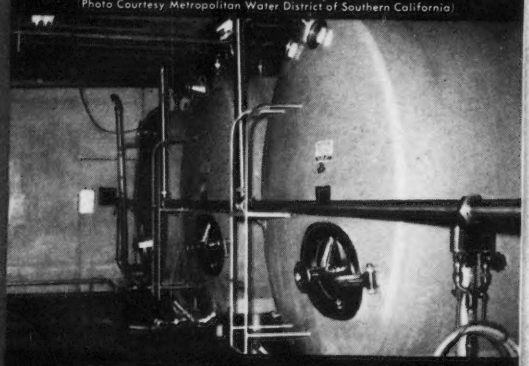
CHEMICAL PLANTS — Caustic Soda Tank



PETROLEUM REFINING — Columns and Piping



WATER SOFTENING PLANT
Photo Courtesy Metropolitan Water District of Southern California



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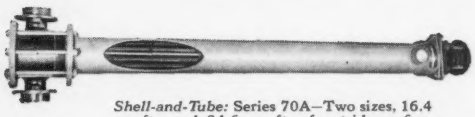
# "KARBATE" BRAND IMPERVIOUS GRAPHITE HEAT EXCHANGERS *FOR ALL PURPOSES!*

The "Karbate" impervious graphite heat exchangers illustrated are used extensively as boilers, coolers, condensers, vaporizers, evaporators, heaters and absorbers in handling corrosive chemicals, either hot or cold. They *all* can be had in a complete size range. *All of them* offer the following advantages:

- **Highest heat conductivity rate of the practical corrosion-resistant materials.**
- **Highly resistant to corrosion by acids or alkalis, hot or cold.**
- **Freedom from corrosion scale, as compared to metals.**
- **Immune to thermal shock.**
- **No contamination of product.**
- **Strong and easy to install and maintain.**

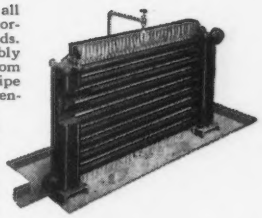


*Shell-and-Tube:* Series 70A—Two sizes, 16.4 sq. ft., and 24.6 sq. ft. of outside surface area respectively. Tubes easily replaced in the field. Interchangeable single and double-pass construction.

*Style FH heat exchangers (Size 1½):* Are especially recommended for tanks with solution depths of 16 inches or less. Write for catalog section S-6750.

Series 240A—70.6 feet of outside heat transfer surface. Easy tube replacement. Easily converted on job to single, double, or four-pass tube side flow by simple change of fixed covers. Steel, shell, over-size shell connections, impingement plates and drain and vent plugs integral with shell end castings. Stainless-steel baffles assembled with steel tie rods to form protective cage for tube bundle. Removable "Karbate" tube bundle. Write for catalog sections for S-6690, S-6715 for details of applications, maintenance, sizes and characteristics of these exchangers.

*Cascade coolers:* For all cooling jobs involving corrosive gases and liquids. Complete cooler assembly may be made quickly from 4 standard items in 5 pipe sizes. Capacity easily enlarged or reduced by adding or subtracting standard sections. Compact construction to save plant room. No special supporting structure needed. Write for catalog section S-6780.



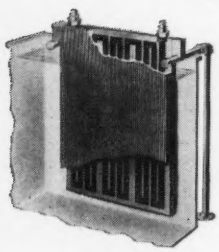
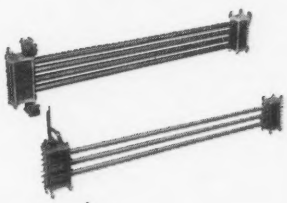


*Plate heaters:* Used to heat or cool corrosive liquids in tanks and vessels. Compact, completely assembled, easy to put in. Used in pickling, etching, plating and cleaning tanks. Complete size range. Models for horizontal and vertical mounting. Write for catalog section S-6620.



*Concentric Tube exchangers:* Available in two types. Series 10A is small, low-priced, gives true counterflow. Exceptionally good for small flow rates at narrow temperature differences . . . Series 20A manufactured with "Karbate" inner and outer piping, and is used to transfer heat between two corrosive fluids. Both have sectional construction, can be added to or subtracted from at will. Sturdy, can be moved from place to place after assembly, adapted to any method of mounting on floor, wall, or ceiling. Write for catalog section S-6670.

*The term "Karbate" is a registered trade-mark of Union Carbide and Carbon Corporation*

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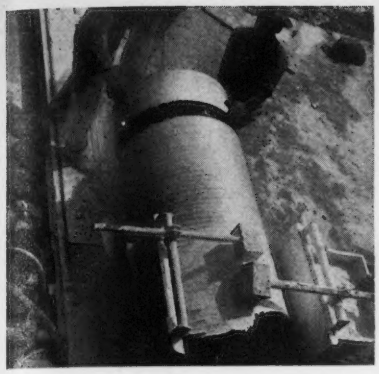

THIS MONTH'S COVER — Whitewash sprays over the hot asphalt-mastic coating applied to this joint of 30-inch pipe at H. C. Price Co.'s plant at Bayou Boeuf near Morgan City, Louisiana. The coupling being removed by the workmen at left will leave nine inches of pipe bare for welding. The weld is covered with a lapped field joint applied by hydraulic or hand mold. The ⅝-inch Somastic coating not only gives corrosion protection but increases the weight of a 40-foot joint of 30-inch pipe by a full ton, an important factor where pipe is being laid in swampy areas.

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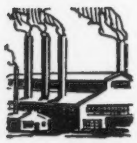

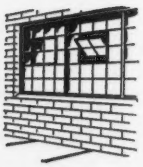

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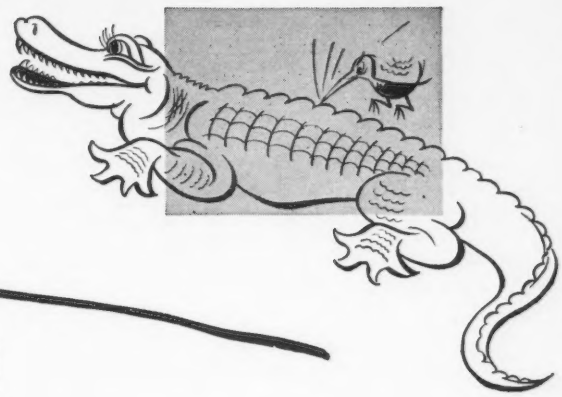

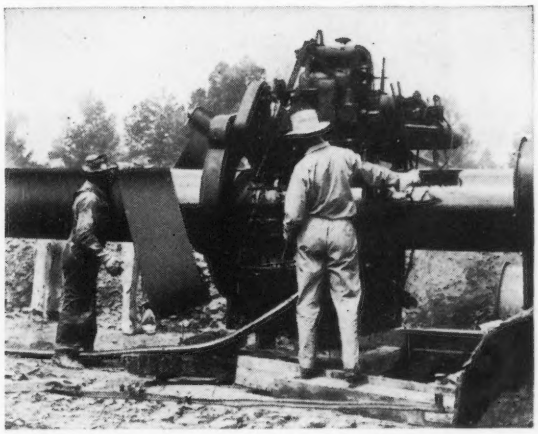

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(a) To promote the prevention of corrosion, thereby curtailing economic waste and conserving natural resources.

(b) To provide forums and media through which experiences with corrosion and its prevention may be reported, discussed and published for the common good.

(c) To encourage special study and research to determine the fundamental causes of corrosion, and to develop new or improved techniques for its prevention.

(d) To correlate study and research on corrosion problems among technical associations to reduce duplication and increase efficiency.

(e) To promote standardization of terminology, techniques, equipment and design in corrosion control.

(f) To contribute to industrial and public safety by promoting the prevention of corrosion as a cause of accidents.

(g) To foster cooperation between individual operators of metallic plant and structures in the joint solution of common corrosion problems.

(h) To invite a wide diversity of membership, thereby insuring reciprocal benefits between industries and governmental groups as well as between individuals and corporations.

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National Association of Corrosion Engineers

An Association of Individuals and Organizations Concerned with Control of Corrosion

919 Milam Bldg. Houston 2, Texas

Vol. 7 July, 1951 No. 7

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TO ALLEVIATE the laborious preliminary work of determining if work already has been done toward solving a corrosion problem and summarizing available information relative to a possible solution the National Association of Corrosion Engineers provides several assists to the investigator. They are:

1. Abstracts published in CORROSION, arranged topically.
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These services are designed to help the researcher progress through the four steps to the solution of a corrosion problem: 1) Determine if a similar problem has occurred, and how it was solved and if the solution was adequate; 2) If the problem is new or unsolved, summarize available information indicating a solution; 3) Plan a program to supply needed data and carry it out and 4) Formulate and apply a solution.

Of the three means provided by NACE related to abstracts, the biennial compilation—Bibliographic Survey of Corrosion—has the disadvantage of containing only abstracts up to three or four years prior to publication date. In this fast-moving technical age, this may prove a disastrous gap to the persons seeking an immediate solution to a serious industrial problem. The abstracts published in CORROSION, while more nearly current, are not adaptable to ready cross-indexing. Clipping these abstracts for pasting on cards to permit cross-indexing proved too great a mechanical problem for most.

The third provision, a service initiated this year, abstracts printed on 5 x 8-inch punch cards, provides a means of semi-mechanical sorting the tools for which are simple, relatively inexpensive, and usable by persons who need not be highly trained technically.

The NACE card provides for punching by code of four topics, and author, journal, date and other indices. A portion of the card is left open for supplementary indexing. The code used is that developed by the NACE Abstract Committee, and is designed to provide a type of indexing suitable to the principal interests of corrosion workers.

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# Bacterial Casing Corrosion in the Ventura Field*

By KEITH DOIG* and A. WACHTER**


## Abstract

The corrosion of well casings in the Ventura Avenue field has become an increasingly important problem during recent years. In the seven-year period since the first leak occurred a total of 40 well casings have failed because of corrosion. A statistical prediction of the future failures now indicates that about 75 percent of the 250 wells drilled between 1938 and 1950 may be expected to fail unless some reduction in failure rate is effected. The inaccessible location of the leaks made it necessary to conduct most of the investigation on a basis of theory, statistics, surface measurements and remote controlled subsurface measurements. In some cases it was necessary to develop new tools in order to make the subsurface measurements. Among the possible causes of corrosion which were considered and, in general, refuted during this phase of the study were particular corrosive strata, defective steel, electric currents in casing or flow lines and interzonal migration of salt water. Concurrent attempts were made to develop means of preventing the failures. The more important methods considered were cathodic protection, insulating flanges on wellhead connections, protective coatings, extra casing strings and full-string cementing. Neither the study of possible causes nor the study of preventives yielded positive results. However, there were some indications that salt water could be migrating behind the well casings. These indications caused the adoption and use on 19 wells of the full-string cementing practice.

The turning point of the investigation occurred when the corroded casing was recovered from one well. This made it possible to minutely analyze the material relevant to the problem including the corroded steel, the corrosion products, the formation adjacent to the leak and the residual drilling fluid cake. The results of the analysis plus further statistical study has led to the conclusion that bacterial activity is responsible for the corrosion which has been experienced. Research has also developed methods for inhibiting or destroying the bacteria. Alkaline environments were known to be inimical to bacterial activity and laboratory and field testing showed that the use of high pH drilling fluids would create such an environment adjacent to the well casings. The testing also showed that, in addition to probably preventing corrosion, the high pH drilling fluids are thoroughly satisfactory from an operational viewpoint. Therefore, this type of fluid is now used for drilling to the casing point in all Shell wells in the Ventura Avenue field. The foregoing partial solution to the problem is applicable only to wells yet to be drilled. To date no proven economical method for preventing bacterial corrosion in the existing wells has been found but study of the problem is still in progress.


## Introduction

THE FIRST CASING leak on which there was enough information to demonstrate that it was due to corrosion occurred in 1943. However, the characteristics of this leak as well as several subsequent failures were obscured by the attention given at the time to collar leaks and split or burst pipe. By 1946 sufficient experience in casing failures had been accumulated to make the distinctive features of the corrosion leaks evident and, because of the increasing magnitude of the problem, an investigation was undertaken. The results of this investigation are discussed in four phases:

1) Operations, including the history, statistics and future trends of the problem and the methods of detecting and repairing the leaks.
2) Past investigations and preventive measures considered, including discussions of the various causative agents and preventive measures studied, the method of study and the results obtained.
3) Determination of the cause of the corrosion, including discussions of the recent investigations and statistical and physical evidence in support of the theory.
4) Preventive measures, including discussions of the measures considered for use in existing and future wells and the recommendations derived from this study.

## Operations

### *History of Casing and Mud Treatment Programs*

The Ventura Avenue field is about six miles long and one and one-half miles wide. Production is obtained from numerous, thick, highly faulted sands of Pliocene age. The early drilling and development of the Ventura Avenue field were slow because of the difficulties encountered in penetrating a shallow zone of relatively high pressure gas and salt water with cable tools. These wells had the multiple casing strings common to cable tool wells. After the transition to rotary drilling, the practice of using an extra string of casing was followed on almost all wells completed prior to 1932. From 1932 to 1940 there was a rather steady increase in the percentage of single string wells. Improved mud control and drilling techniques and relaxation of some legal requirements permitted the change in procedure to be made. Since 1940 about 90 percent of the wells have had only one casing string.

The drilling fluid system and treatment methods are also of interest. The clay is obtained from the Dent mud mine about one mile south of the field, mixed with water and pumped to a reservoir above the Taylor Mud Plant. When mud is required, it is taken from the reservoir into the plant, treated chemically and pumped to the wells. When the wells no longer require water-base mud, it is pumped back to the Taylor Mud Plant for storage and re-use. Methods of treating the mud have undergone many changes over the years. Prior to 1934, little or no chemical treatment was used and when the mud

* A paper presented at the Seventh Annual Conference and Exhibition, National Association of Corrosion Engineers, New York, N. Y., March 13-16, 1951.

* Shell Oil Company, Ventura, Cal. ** Shell Development Company, Emeryville, Cal.

became unsuitable for further drilling it was discarded. In 1934, the caustic soda-quebracho-sodium silicate treatment came into use. This treatment resulted in a mud having a pH of about 10. In the period from 1938 to 1940, the mud treatment was changed to the phosphate-quebracho method. This was done because the mud treated in this manner was relatively stable and easily controlled. One of the results of changing the treatment was to produce a mud having a pH of about 8.5.

*Classification, Detection and Repair of Leaks*

The first failure that can definitely be attributed to corrosion occurred in 1943. However, it is possible that there were earlier leaks which cannot be recognized now. The significance of the earlier failures was missed for a time because of the attention being given to the mechanical type of casing failures which were encountered in connection with the completion of some of the first high-pressure D-7 Zone wells. Hence, there were several failures due to corrosive attack before an investigation was undertaken. After sufficient experience had been accumulated, a study of all the casing failures was made. They were divided into three general groups:

1) **Mechanical Failures:** This group includes leaks due to burst, split, or collapsed pipe. Mechanical failures are usually distinguished by difficulty in getting tools past the failure point. For purposes of this investigation the mechanical failure group also includes those wells in which it was not possible to set a packer over an interval of several feet in the region of the hole, the assumption being that when the hole extended several feet it was either a split or could be attributed to drilling wear. Some of the wells that were included in this group may actually be corrosion leaks, but these doubtful wells were classed as mechanical rather than corrosion leaks in an attempt to clarify the corrosion data and to aid statistical analysis of this problem.

2) **Leaks at Collars:** These may be leaks along the threads. However, it is more probable that they are due to corrosion at or immediately adjacent to the collars. At present, there is no method of distinguishing between thread leaks and corrosion leaks at the collars, but all the collar leaks are assumed to be due to corrosion for the purposes of this study.

3) **Leaks in the Body of the Pipe:** The nature of these holes can be explained only on the basis of some type of corrosion. Cementing tools pass the leak areas readily and may be set sufficiently close to the hole to determine that the leak area is less than one foot in extent. In addition, there have been cases where a hole was eroded in the tubing by fluid entering through the leak. The localized area of the tubing hole, one to one and one-half inches in diameter, was taken to be an indication of the size of the casing hole. Some of the wells have developed two or even three leaks practically simultaneously. The corrosion has always been assumed to be external to the casing since external corrosion of tubing, which would probably be related to internal corrosion of casing, is virtually nonexistent in this field. This investigation, being primarily interested in casing corrosion, has considered the body leaks and the collar leaks only to the extent that they might have been caused by corrosion. The thread leaks and the mechanical failures constitute a different problem.

Leaks are most commonly detected when a well starts producing mud or salt water although they sometimes are associated with gas or oil escaping from the casing. This latter type of leak is detected because of the resultant abnormalities in the casing or bottom-hole pressures. On three occasions the escaping gas has caused surface blowouts of gas and salt water by driving salt water upward in the annulus between the casing and the hole. As soon as possible after detection of a leak, the well is killed with mud. This is necessary because it has been found that the salt water and sand entering through a leak can erode a hole in the tubing, almost severing it, in less than twenty-four hours. In about the same time, the tubing may become sanded up and stuck, particularly on wells in which the tubing extends into the liner.

On a simple repair job, assuming that the tubing is free and there are no other complications, the procedure is as follows:

1) Locate the leak by pressure testing between the surface and a single packer. The test pressure is usually about 1000 psi. By this method, it is readily possible to determine the location and extent of the damage to within less than one foot.
2) Run a collar survey to determine whether the leak is in the body of the pipe or at a collar. This is done solely for information and is not necessary for repair procedure.
3) Cement the leak with a straddle tool. The leak is tested and, if necessary, recemented until it will hold a pressure of about 1500 psi.

The repair procedure has been very satisfactory. During the seven years that this method has been used, there has been only one well wherein the hole could not be successfully cemented and, in this case, it was necessary to install an inner casing string. It is significant that in the wells which have failed and been repaired there have not been any additional corrosion failures.

## Statistical Data

Some of the more important statistics (for Shell wells only) in regard to casing corrosion are as follows:

1) In the past seven years, 40 wells have developed casing leaks.
2) In the 38 wells which have been repaired to date there were 45 casing corrosion leaks in the body of the pipe and 9 leaks at or near collars.
3) These leaks range in depth from 905 feet to 7085 feet.
4) The average time between completion of a well and the development of a leak is about 55 months with a range from 11 months to 136 months.

A point of some interest is the estimation of the

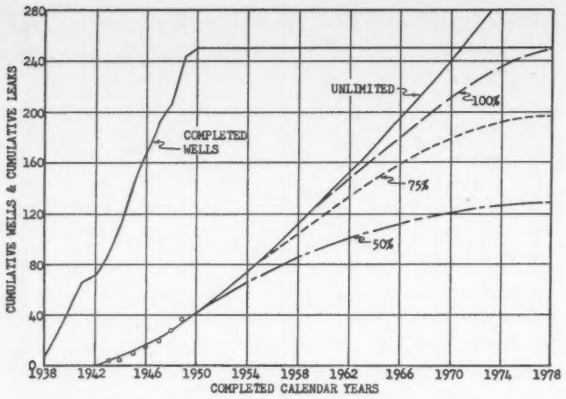


**Figure 1—Estimation of future corrosion problem.**

future trend of the corrosion problem. By manipulating the relatively limited data on past failures so as to eliminate the effect of new wells added by drilling which otherwise cause the failure rate to seem too low, it is possible to obtain curves shown in Figure 1. The four curves are based respectively on an unlimited number of failures, 100 percent failures, 75 percent failures and 50 percent failures. The problem of selecting the most representative curve is difficult because of the lengthy extrapolation. However, the previously-mentioned fact that there have been no repeat failures tends to discount the unlimited failure curve and to establish the upper limit at 100 percent. The lower limit may be considered as 50 percent because the wells in certain older age groups have already had nearly a 50 percent failure experience. Having tentatively established the limits, the future failure expectancy of 75 percent is presented as being a reasonable approximation of what may occur, largely because it is midway between the limits. The limited data probably prohibit determining the ultimate failure percentage with greater precision.

## Past Investigation and Preventive Measures Considered

### *Investigations*

Investigation of the cause of any corrosive attack is often difficult and the study of casing corrosion is made more difficult because of the inaccessibility of the failure points. Until very recently, it had never been considered practical to recover the corroded pipe because of the hazard of losing the well in the process. An attempt to recover a leak at 905 feet in Taylor 176 was thwarted because of the presence of abnormally high-pressure salt water. This prevented study of the physical and chemical characteristics of any of the corroded areas. Therefore, the initial portion of the investigation was conducted primarily on a statistical basis. The first point studied was the relationship between the location of the leaks and the subsurface geology. The idea that some particular stratum or the fluid therein was corrosive was readily disproven by this phase of the investigation. There is no correlation between the holes and any particular stratum. Of the 54 known leaks 40 occurred at salt water sands, six at faults and eight at shale bodies. None of the leaks appears to have occurred at an oil sand.

Another line of investigation suggested by statistics was casing metallurgy. Part of the reason for this idea was the high incidence of leaks in a particular make of welded casing. Of the 54 leaks, 24 or 45 percent have occurred in this type of pipe. During the past ten years only about 20 percent of the wells used this type of casing. The other reason was that many of the failures were in pipe manufactured during the war. Thorough chemical and metallurgical examinations indicated that, in spite of the statistics, there were only slight differences in the resistance to corrosive attack by the various grades and types of pipe. The possibility of local heterogeneities in the metal at the actual leaks remained but was not provable at that time. Electrochemical tests showed that the potentials between different grades and makes of casing in an electrolyte were negligible. The tests were made using deaerated Ventura brine as the electrolyte.

Measurements of the electric current in the flow lines were made at numerous wells. These currents were found to range from 3.5 amperes flowing into one well to 1.4 amperes flowing out of another. About 25 percent of the wells measured had current flowing out through the flow line. However, the leaks have occurred regardless of the direction or magnitude of the flow line current. A recording voltmeter was run on several wells for cyclic variation in flow line current, but no such variation was found.

Inasmuch as statistical and surface investigations were unrewarding, other avenues of approach to the problem had to be tried. Information received from other fields having a similar problem plus the fact that failures seemed to be spreading from two focal areas in the field indicated that migrating salt water could be a contributing factor to the corrosion. Temperature surveys were run in a few wells which had developed leaks and had been killed with mud. These surveys showed only slight variations from the normal temperature gradient. More recently, temperature surveys were run in an endeavor to discover leaks and some of them showed discontinuities in thermal gradient as may be seen in Figure 2. However, the variations are rather small and there is some question as to whether or not they are significant.

Because of the inconclusive results obtained with the early temperature surveys it was necessary to develop some other hypothetical cause of corrosion. The possibility that electric currents, either introduced through the flow line or generated by formations of different potentials, were flowing along the casings for distances of several feet was adopted as a working theory. In order to test this hypothesis it was necessary to develop a tool which would measure currents in the casing at any depth. The first tool tested consisted of a single electrode run on standard electric logging cable. Contact with the casing was established by use of sliding, spring-loaded knife edges. This tool gave a continuous recording of electrical potential with respect to the casinghead potential. In Figure 3 is a sample of one of these voltage surveys. In order to interpret this log in terms of

electrical current it is necessary to take the differential of the curve graphically. Because of the very slight differences in gradient and difficulty in obtaining good electrical contact, the total potential type of log obtained with a single electrode tool was considered unsatisfactory.

The doubtful results obtained with the single electrode survey stimulated an effort to develop a two-electrode tool which would give a continuous log of potential difference across a fixed span. Several different contacting and amplifying arrangements were tried. Although it was possible to obtain good continuous survey results in tests made on empty casing laid on the surface, it was impossible to obtain good continuous contact with the casing when the tool was run in a well. Therefore, it was necessary to adopt a spot reading type of survey. On this basis the present equipment was developed into a reasonably satisfactory field instrument. The device (see Figures 4 and 5) consists basically of two modified mechanical slot cleaning tools. Each of these tools constitutes one measuring electrode. They are hung fifty feet apart on electric logging cable and the actual contact with the casing is established by the twelve spring-loaded blades mounted in each electrode. The blades point in the direction opposite to that in which the tool is traveling. Since the springs are sufficiently strong to support the weight of the tool when the blades are pointed downward, it is necessary to run the instrument all the way to the desired total depth, pull up and turn the blades over and start out of the hole. It is impossible to go back down after starting upward and readings are always taken while pulling out of the hole. The best procedure is to stop at the depth where a reading is desired and then slack off a few feet. This throws the weight of the tool onto the points of the contactors and achieves good electrical contact with the casing. In addition, it has been found that better contact is obtained with oil-base mud or oil in the well than with water-base mud.

The current input contactors are shown in Figure 6. These are used to introduce a measured current across the measuring electrodes. By observing the effect of this calibration current it is possible to check the resistance of the casing between the electrodes.

Before the first tests were run with the differential voltage survey tool, an arbitrary polarity convention was adopted and the meters were installed so that the data conform with this convention.

1) Positive values indicate that current is flowing up-

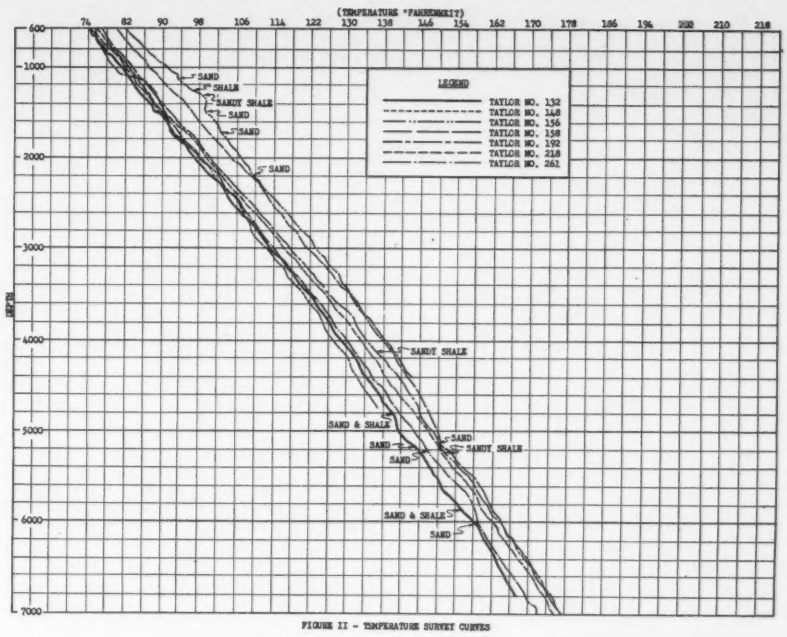


FIGURE II - TEMPERATURE SURVEY CURVES

Figure 2—Temperature surveys showing thermal gradient discontinuities.

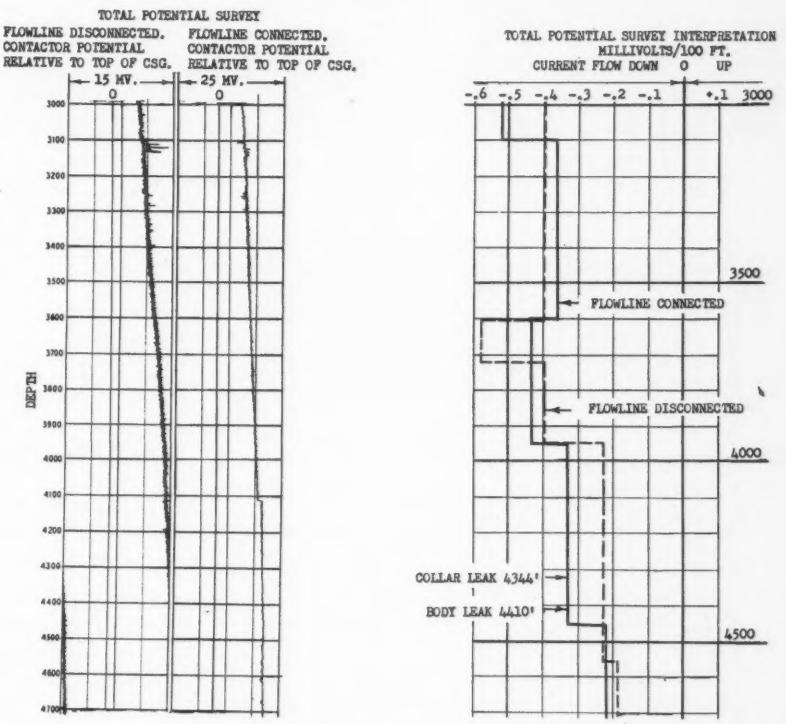


Figure 3—Voltage surveys with single electrode tool.

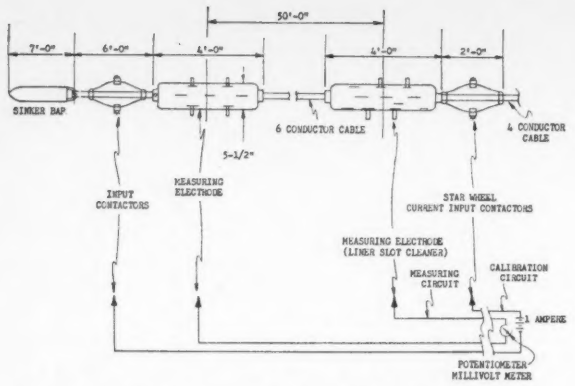


Figure 4—Schematic diagram of two-electrode voltage survey tool.

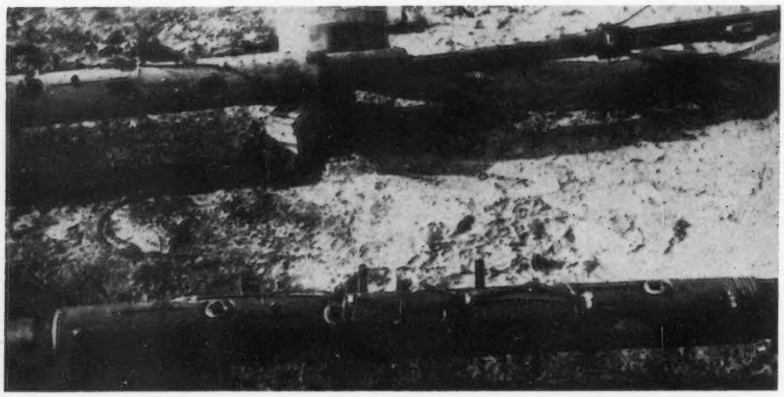

Figure 5—Two-electrode voltage survey tool.

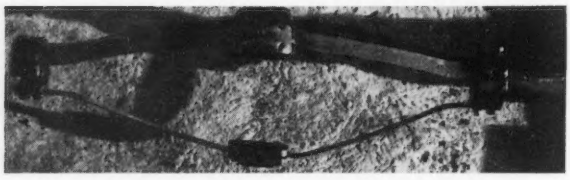

Figure 6—Current input contactors, two-electrode voltage survey tool.

ward and negative values indicate that current is flowing downward.

On this basis, the next rule in regard to the curves may be stated as:

2) Positive slopes indicate that current is entering the casing and negative slopes indicate that current is leaving the casing.

In interpreting the detail readings taken at 10-foot or 20-foot intervals there are some additional facts which must be taken into consideration. These arise because the readings taken with this tool are not point values, but summations of the conditions existing within the 50-foot interval between the contact points. These rules, which may be proven mathematically, are:

1) Both electrodes in constant resistance pipe carrying constant current, result in a line of constant current.
2) In constant resistance pipe the electrodes, passing across a point of current change, result in a line of constant slope from the point at which the top electrode passes the point of change to the point at which the bottom electrode passes it.
3) In constant resistance pipe, the electrodes passing an area of constant current change:
   (a) If the interval is shorter than the electrode spacing, it results in a curved line of vertical length equal to the length of the area of change, followed by a line of constant slope, followed by a curve of the same length as the first curve.
   (b) If the interval is longer than the electrode spacing, it results in a curve, shaped as above, but the vertical length of either curved portion would equal the electrode spacing and the vertical length of the interval would equal one curved portion plus the straight portion.
4) If, in pipe carrying constant current the resistance changes, the resultant effect would be the same as that obtained with a point change of current.

Tests have been run at Taylor 157 and Taylor 169 in order to check the electric current hypothesis. The logs obtained from these tests are shown in Figures 7 and 8. Also shown in Figure 7 is the graph of a survey made in Taylor 157 shortly after the leaks were cemented. The general significance of these curves is discussed below.

The data from Taylor 157 before cementing show that current is entering the casing in the region of the leak. However, it is possible that there were small localized currents circulating on the outside of the casing which were not detected by the survey. The run after cementing was made primarily to check a belief that cementing caused a change in the current distribution. The fact that there was such a change is obvious from a visual comparison of the two curves. The curve obtained from Taylor 169 (Figure 8) indicates that current is leaving the casing in a fairly uniform manner in the area where the leak developed. However, analysis of the data taken at 10-foot intervals shows that current is not leaving at the leak. The solid curve in Figure 9 shows the actual data and the dotted curve shows the probable true current distribution. The reason for the difference is that, as pointed out above, the readings taken with this tool are summations of the conditions existing within the 50-foot electrode span.

The curve shown in Figure 10 is of the approximate shape that might be expected if the flow line current were a major factor in causing the corrosion. Assume that one ampere flows into the well through the flow line. This current would split between the surface casing and the water string approximately in proportion to the weight per foot of these casings. At the shoe of the surface casing, current would flow into the water string from the surface string. The current in the water string would then be equal to the flow line current less any current lost from the surface casing to the formation. The current would flow downward, experiencing some loss to the formation, until it reached the depth at which the

leak occurred. At this point a fairly large part of the casing current could be expected to flow into the formation. Since none of the voltage surveys which have been run have produced a curve of this type, it might be concluded that flow line current plays little or no part in the corrosive attack. Several surveys have been run in order to support the theoretical conclusion with field data. The surveys were made by taking readings at various depths with the flow line connected and disconnected. All of these surveys indicated that the rate of change of casing current at depths more than a few hundred feet below the surface was unaffected by reducing or eliminating flow line current.

It can be concluded from the voltage survey test results that, although electric currents do enter and leave the casing, they appear to do so in a fairly uniform manner and do not necessarily leave the casing at measurable rates at the points where corrosive attack occurs. The existence of local cell action is possible but is not measurable with present methods and equipment. The surveys also discount the importance of flow line current as causative agent.

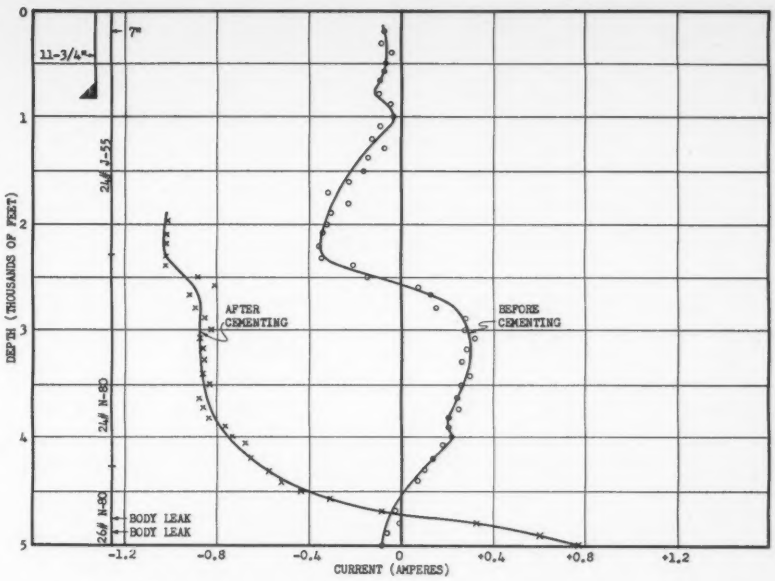


Figure 7—Log of electric current survey results from Taylor 157.

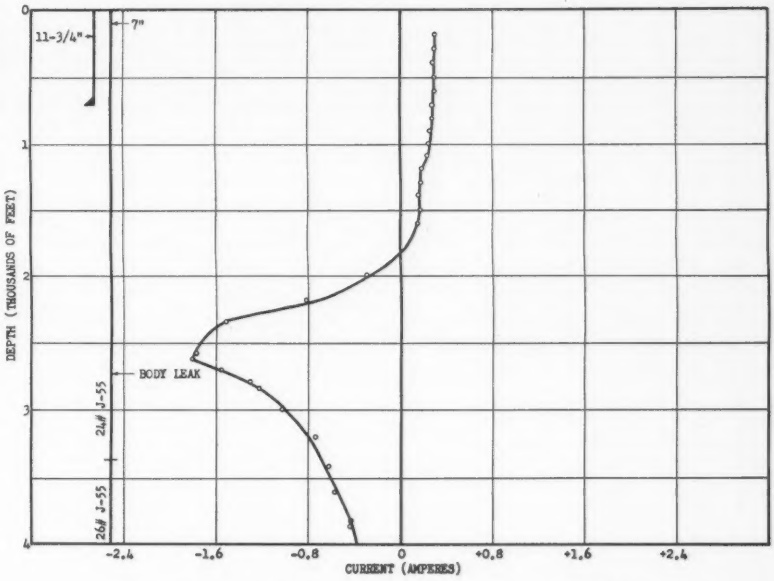


Figure 8—Log of electric current survey results from Taylor 169.

*Preventive Measures Considered*

Many preventive measures were studied during the investigation. However, because of uncertainty as to the cause of corrosion, it was difficult to know which method to try. In addition, all of the preventives themselves were experimental, at least in this application. Thus it would be necessary to try to decide on the best possibility both from a mechanical and economic standpoint and embark on a large-scale program of installing that particular preventive. Thereafter, it would be necessary to wait five or six years before it could be determined if the method were successful. The problem of selecting the right preventive was further complicated by the fact that it was possible for a method intended to prevent the failures actually to aggravate the situation.

There were only two methods discovered in the course of the past investigation which would be applicable to both existing and new wells. These were:

1) Insulating flanges on the flow lines and other wellhead connections, and
2) Cathodic protection.

As discussed previously, it is doubtful that flow line currents are a major factor in causing casing corrosion in the Ventura field. Therefore, it was concluded that insulating flanges to reduce the flow line current would be of little or no value and their installation was not recommended.

A test of cathodic protection was made on one well in the Ventura Avenue field. From this test it was concluded that cathodic protection could not be readily applied to existing wells for the following reasons:

1) The current induced in the water string flows upward and divides at the shoe of the surface pipe, a part of the current flowing from the water string to the surface pipe. This would probably result in severe electrolytic corrosion on the outside of the

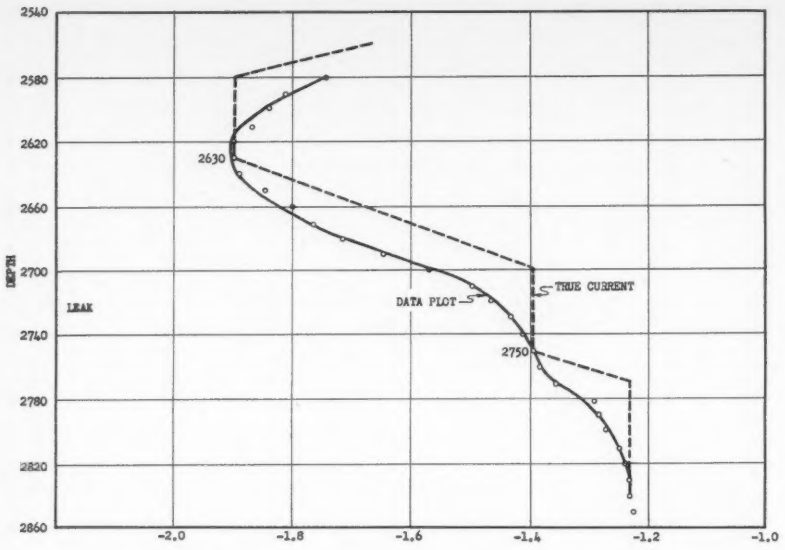


Figure 9—Analysis of data from Taylor 169 showing current is not leaving at the leak.

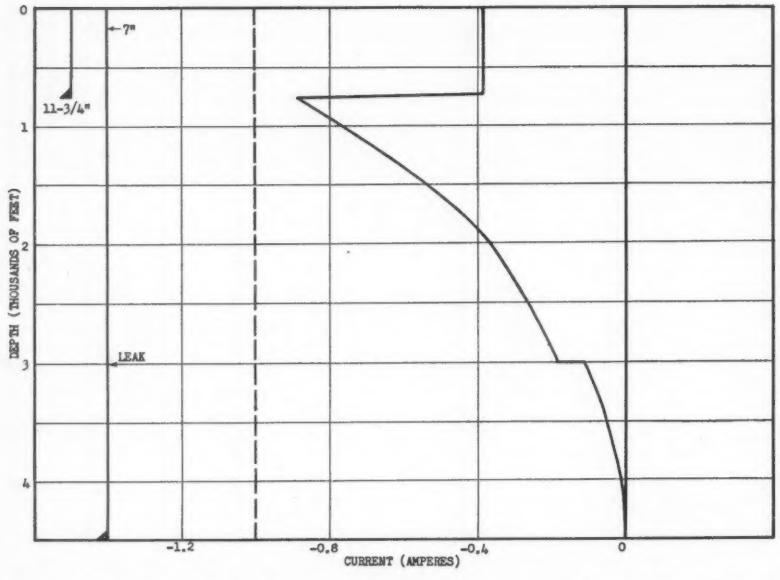


Figure 10—Approximate shape of curve to be expected if flow line current were a major factor in corrosion of Taylor 169.

water string at the point at which current leaves.

2) The effective depth of protection was not great enough.

3) The economics of cathodic protection are probably unfavorable on deep wells because of the large power requirements.

The cathodic protection test was run at Taylor 148, a well in which two leaks had been found and repaired by cementing. In order to obtain as much information as possible in one test setup, two anodes were used. The far anode consisted of 40 feet of 10-inch pipe buried in the ground 1000 feet east of Taylor 148. The near anode consisted of 20 feet of 10-inch pipe submerged in a small mud sump 320 feet west of the well. A welding machine was used as the source of direct current for the test. By means of switches, it was possible to change readily from one anode to the other. The voltage survey tool, described previously, was used in making the necessary subsurface measurements. Figure 11 illustrates the electrical circuits used in the test.

Figure 12 illustrates the curves obtained from the data taken during the test. The data for the curve showing the casing current before the application of cathodic protection and the data for determining the casing resistance were obtained on the first test run. The data show that current is flowing down the casing over its entire length. From the surface down to slightly above the shoe of the surface pipe there is little change in current. At the shoe of the surface pipe about 0.5 amp. enters the 7-inch casing. From 695 feet to 1800 feet an additional 0.7 amp. enters. From 1800 feet to 3300 feet, 1.7 amps. leave the casing and from 3300 feet to 4700 feet, a total of 0.5 amp. enters the casing from the formation.

On the second run readings were taken at each depth while applying cathodic protection first with the far anode and then with the near anode. Both curves indicate that current is flowing up the casing throughout its length. The data show that below 4300 feet, the current is leaving the casing at the rate of about 0.03 amp. per 100 feet regardless of the differences in anode spacing and cathodic current. A current penetration of 4300 feet is inadequate since about 45 percent of the leaks have been below that depth. From 4300 feet up to the contact point established by the first test at 695 feet, the current enters the casing, reaching a maximum of 21 amps., with the far anode and 17.5 amps. with the near anode. At 695 feet currents of 10 amps. and 8.5 amps. with the far and near anodes, respectively, flow from the 7-inch casing to the 11¾-inch casing. The fact that this could cause extreme corrosion of the 7-inch casing may be readily seen. Above 695 feet the current flow is very complex with several points of current transfer.

As a result of these tests it was concluded that cathodic protection is not a practical method for preventing leaks in existing wells in the Ventura field.

Although there seemed to be no practical means for preventing corrosion of casings of existing wells,

several methods were studied which would be applicable to wells yet to be drilled. These were:

1) Protective coating of the casing.
2) Protective coating combined with cathodic protection.
3) Protective strings of casing.
4) Filling the annulus behind the casing with oil-base mud.
5) Chemical corrosion inhibitors.
6) Full-string cementing.

The protective coatings are widely used for preventing corrosion. Metallic coatings or pipe made of high alloy steels were rejected because of high cost and unavailability. However, the organic coatings appeared to have some potentialities. Several materials have been considered and two field tests have been made. The first test was made by coating two joints of 7-inch casing with a standard high-temperature coal tar enamel. These joints were made up and lowered to a depth of 7500 feet on the string of drill pipe and then pulled from the hole. Inspection of the coated joints after the test showed that about 15 percent of the material had been scraped off and the remainder had softened and run because of high well temperatures. The second test was made with a specially prepared high-temperature coal tar enamel. It was tested in the same manner as before, except that the casing was run in to 8000 feet. One of the joints was single-coated and the other joint was double-coated. Tests were made with a holiday detector before running in the hole and all the imperfections were repaired. The damage caused by handling before running was also noted. After the pipe had been pulled from the hole it was retested with the holiday detector. The single-coated joint had suffered 13 scratches or gouges which penetrated the coating while the double-coated joint had only two such defects. The total metallic area thus exposed was only about four square inches. The photograph in Figure 13 shows two of the scratches. Most of the damage caused by handling could be avoided, and any such damage, as well as areas to which tongs and slips were applied, could be repaired just before the casing was run in the hole.

This coating material may be considered successful in that it showed only slight softening at the 185° F temperature encountered at 8000 feet and only a small area of the coating was damaged by running in the hole. However, it was feared that localized damage to the coating would cause concentration of the corrosion. It has been suggested that some wrapping material be used in connection with the coating. The desirability of this procedure is questionable because

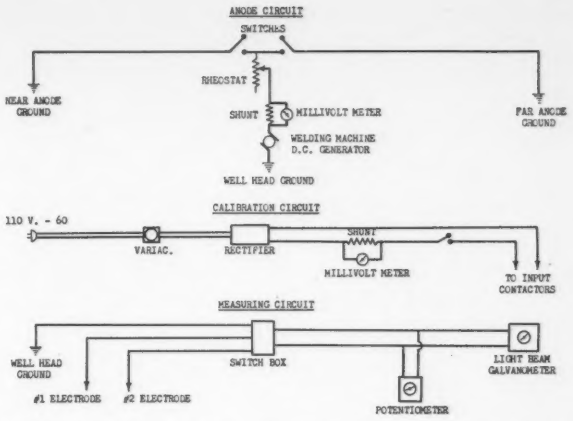


Figure 11—Electrical circuits used in testing cathodic protection of Taylor 148.

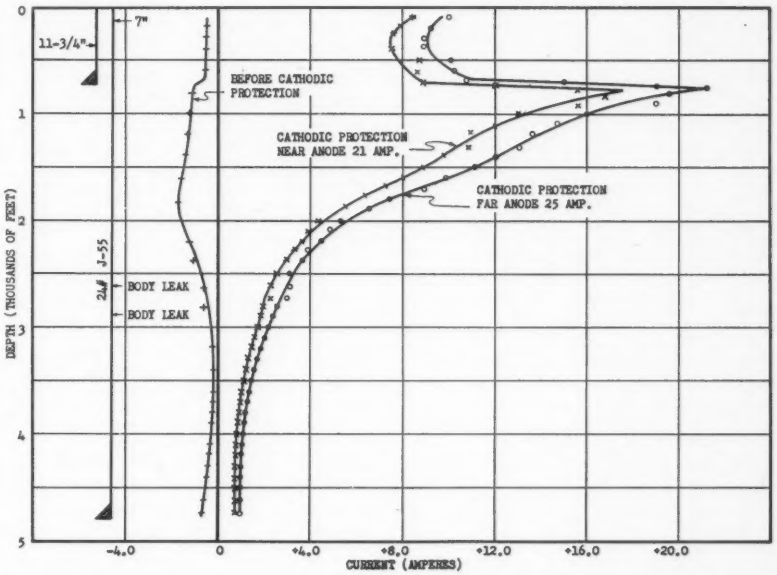


Figure 12—Curves obtained from data taken during test of cathodic protection of Taylor 148.

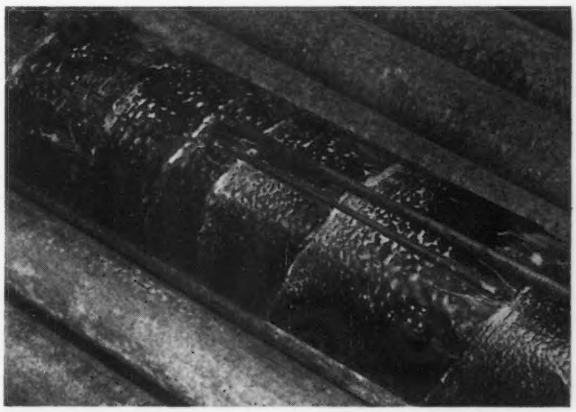

Figure 13—Two of the scratches in coated joints used in investigating feasibility of protecting casing with exterior application of coal tar material.

of the possibility of the material unwrapping and sticking the casing during the running operation.

The use of cathodic protection in connection with the coal tar coating would probably overcome the possibility of localized corrosion at the points where the coating is damaged. The coating would reduce the electric current required and increase the effective depth of the protection. It would be necessary to take care of the current transfer problem at the shoe of the surface casing. This could be accomplished by assuring a good metallic bond at the transfer point, by having a very good insulation between the two strings of casing or by using the tubing as a conductor. Since adjacent existing unprotected wells and surface pipe lines might be damaged by stray currents introduced by the protection equipment, the installation of coated casing and cathodic protection was neither further tested nor recommended.

The use of an extra string of casing, either 9⅝-inches or 11¾-inches, in reality another form of metallic coating, in addition to the usual 7-inch or 7⅝-inch casing was thought to be a reasonably certain method of preventing leaks. High costs and unavailability of casing were drawbacks and the plan of using extra casing was not tried for corrosion prevention.

The basic reason for considering the use of oil-base mud in the annulus is that the oil-base mud has high electrical resistance, i.e., it would act as a pipe coating. To obtain the maximum benefit from the oil-base mud it would be necessary to install centralizers on the casing to center the casing in the hole as much as possible. The objection to the use of oil-base mud, in addition to the relatively high cost, is that it might not be permanent. There are some instances in which the water-base mud ordinarily left behind the casing has been displaced by salt water. Since there is no reason to believe that the oil-base mud would be a great deal more resistant to displacement than the water-base mud, the use of oil-base mud was not recommended for this purpose.

The use of some chemical corrosion inhibitor was another idea for preventing the corrosion. Two possible ways in which a material of this type might be applied are:

1) The inhibitor could be placed on the surface of the casing as it is run in the hole, or
2) It could be added to the mud system immediately before cementing.

The use of inhibitors was considered and laboratory tests were made. On the basis of these tests, it was possible to draw some tentative conclusions:

1) The material would be quite costly in the quantities required when used as a mud additive.
2) It is doubtful that an inhibitor would have the persistence necessary to insure permanent protection of the casing.
3) It is important that the mechanism of the corrosion be known in order to select the correct inhibitor.
4) Most inhibitors are detrimental to the physical properties of drilling fluids.

In view of these considerations the outlook for successful use of inhibitors was not encouraging and work on the subject was discontinued.

The use of cement in preventing corrosion was one of the first ideas considered in the course of the investigation. However, the concepts of how it should be applied and how it would act as a preventive have changed during the study. Initially, it appeared that the cement would be desirable only if a complete and fairly uniform annulus sheath of cement could be obtained around the casing. In order to approach this goal it would be necessary to use scratchers and centralizers at close intervals along the entire length of the casing and to displace the cement through cementing collars in stages. Estimates which indicated that the cost of this operation would be very high, plus the belief that some channeling of the cement through the mud would be unavoidable, caused the use of the idea to be deferred. More recently, the idea was reconsidered because some of the temperature surveys did show variations which might have been due to migrating salt water. The newer concept was that it would only be necessary to secure a water shutoff at a few selected shale bodies, thus preventing extensive migration, in order to prevent corrosion. This conclusion, in turn, was based on the best information available at the time. The applicability and economics of this procedure were greatly improved by the development of a light-weight cement slurry. The use of this type slurry is important in prevention of lost circulation and in keeping pumping pressures low by reducing the differential pressure gradient between the casing and the annulus.

Extensive tests were made in mixing a cement slurry to a density of 85 pounds per cubic foot using 15 percent bentonite and construction cement. These tests showed that such a slurry could be mixed without having settling or free water and that standard cementing equipment could be used by adding an extra water line into the mixing hopper. The important properties of the lightweight slurry are given in Table I.

The procedure which was finally decided upon was to:

1) Run a caliper survey to determine the volume of slurry required to fill the annulus.
2) Select several shale bodies from the electric log. The casing string was then arranged so that at least one joint having six scratchers and two centralizers was located at each of the selected shale bodies.
3) Mix the slurry to a weight of about 5 pounds per cubic foot in excess of the mud weight using an excess of about 5 percent over the volume required to fill the annulus to the surface as determined from the caliper survey data.
4) Follow the low strength, lightweight cement by 200 sacks of normal slurry mixed to about 120 to 125 pounds per cubic foot. This would give the desired strength around the casing shoe.
5) Displace the cement in the conventional manner and reciprocate the casing until the displacement was completed or until the casing stuck.

The first job was cementing 7-inch casing at 5200

**TABLE I**

**Properties of Lightweight Cement**

| | |
|---|---|
| Density | 85#/ft.³ |
| Bentonite | 15% by weight of cement |
| Water | 2.8 ft.³/sack of cement |
| Slurry volume | 3.1 ft.³/sack of cement |
| Stormer viscosity | 220 grams |
| Compressive strength (5 days) | 200 psi. |
| A.P.I. thickening time | 4 hours |

feet. Inasmuch as that job was mechanically successful, deeper jobs were tried in order to test and prove the procedure. The deepest of the 19 full-string cement jobs done was cementing 7-inch casing at 10,699 feet. Circulation was maintained all during the operation, cement returns were obtained at the surface, and no difficulties were encountered. Incidentally, it was noted that the casing became immovable before the cement could be displaced on most of the jobs.

Although the past investigation was admittedly not productive of really positive results, either as to the cause or the prevention of the corrosion, it has been presented in some detail. This was done because the negative results may be used, by a process of elimination, to help determine the actual cause. The data from some of the phases of the investigation such as current surveying, cathodic protection, full-string cementing, etc., may also be of value in attacking problems encountered elsewhere.

## Determination of the Cause of the Corrosion

### *Recent Investigations*

The most important development in this entire investigation occurred when the corroded casing was recovered from Taylor 132. This well was completed with 11¾-inch surface casing cemented at 701 feet, a water string of 7-inch T & C flash-welded pipe cemented at 6800 feet and a 5-inch liner from 6774 feet to 8252 feet. About eight years after completion a leak developed in the 7-inch casing and the influx of salt water and sand stuck the tubing in the liner. The leak was located at 2395 feet by testing with a packer. Since this was relatively shallow and the increasing seriousness of the corrosion problem made more information essential, the casing was washed over and recovered to a depth of 2532 feet. In addition to the recovered casing, samples of the formation adjacent to the leak, the scale in the corroded areas, the mud cake adhering to the casing and the drilling fluid used to wash over were taken. These materials were subjected to intensive analysis.

Visual inspection was made on all the casing which was recovered. As was expected, no significant internal corrosion was found, but most of the joints of casing below the shoe of the 11¾-inch casing had suffered superficial localized external attack. Most of the external surface was in excellent condition, virtually as good as new. The actual leak (see Figure 14) was oval-shaped and about 1½ inch x ¾ inch in size and appeared to have been eroded by the influx of sand and salt water. All of the major corrosive attack was within a distance of about two feet on either side of the leak. Most of the pitting was on the same side of the pipe as the leak although one deep pit was present about 150° around the casing from the leak. This same generally linear corrosion also typified the minor corrosion on the other joints. Since there was no correlation between the corrosion band and the seam in the casing it was concluded that the pits corresponded to the contact areas between the casing and the wall of the hole. The extremely low rate of metal removal (0.345 inches in eight years) indicates that the rate of change of current flow along the casing at the corroded area would not be measurable with the current survey equipment.

**Figure 14—Actual leak in casing recovered from Taylor 132. Hole has been eroded by influx of salt water and sand.**

**TABLE II**

**Comparison of Corrosion Product Analyses**

| Component | Analysis of Casing Scale | Reported Analysis of Bacterially Corroded Buried Pipe Lines (1) | | | Calculated Composition of Casing Scale | |
|---|---|---|---|---|---|---|
| | | No. 1 | No. 2 | No. 3 | | |
| S— | 1.38%W | 1.71 | 1.92 | 1.15 | FeS | 6%W |
| $SO_4$— | 0.31 | 0.90 | 1.32 | None | $FeCO_3$ | 53 |
| $BaSO_4$ | 0.3 | .... | .... | .... | $Fe(OH)_2$ | 16 |
| Total S | 2.7 | 2.06 | 2.44 | 1.20 | Hydrocarbon | 2 |
| $F^{+++}$ | 0.6 | 0.1 | 1.4 | 2.1 | Acid. insol. | 11 |
| Total Fe | 38.8 | 34.0 | 28.4 | 39.6 | Unaccounted | 12 |
| $CO_2$ | 20.3 | 8.4 | 10.6 | 18.0 | | 100 |
| C (wet oxid.) | 7.3 | .... | .... | .... | | |
| Acid insol | 10.6 | .... | .... | .... | | |
| $SiO_2 + Al_2O_3$ | .... | 32.6 | 42.1 | 12.6 | | |

The physical appearance and relatively low pH, about pH 8.3, of the mud cake adhering to the casing showed that it was the residue from the mud originally used to drill the well. The drilling fluid used in washing over and redrilling was about pH 12.

Metallurgical analysis of the corroded casing showed that there was no evidence of inferior quality pipe nor were there any heterogeneities which might cause or accentuate the corrosion. Although the results of the metallurgic and visual examinations of the recovered casing did not produce positive answers, the results from other tests discussed below permit a reasonably positive conclusion on the cause of casing corrosion.

### *Evidence that Casing Corrosion Is Due to Bacterial Activity*

A chemical analysis of the corrosion products, a brittle, black scale obtained from the pitted casing near the leak, was made. The results of this analysis showed that the constituents of the scale were strikingly similar to those reported in cases where sulphate-reducing bacteria were known to be the principal cause of corrosion on pipe lines (see Table II). The presence of 6 percent ferrous sulfide is particularly indicative of active bacteriological corrosion because it is well established that the sulfur content of steel (API standards require less than 0.06 percent)

is insufficient to account for the quantity found in the products of bacterial corrosion. Consequently, additional sulfur must be made available from some foreign source, and since the formation water in this field contains almost no sulfide, it is reasonable to conclude that the necessary sulfur is made available by bacterial reduction of the sulfates present in the earth, water and drilling fluid. Another important indication in regard to the possibility of bacterial activity is the relatively small amount of iron in the ferric state in the corrosion products. This shows that oxygen was virtually absent, an essential condition to the growth of the anaerobic sulfate reducing bacteria. Furthermore, the absence of oxygen generally suppresses corrosion in nonacidic aqueous media unless there is some other depolarizing agent such as bacteria present.

As previously mentioned, the pH of the residual mud cake was about 8.3. The generally accepted limits for activity of sulfate-reducing bacteria are pH 5.5 and pH 9.[2] Therefore, the pH and degree of anaerobiosis were determined to be favorable.

The localized nature of the attack on the casing is also typical of bacterial corrosion.[2] It has been noticed that the bacteria tend to form rather tightly-knit colonies rather than dispersing evenly throughout an entire system. By this concentration of activity, the bacteria, through their metabolic processes, are probably able to control their environment to some degree.

Statistical data may also be developed to support the bacterial theory. It is found that a serious corrosion problem exists only in wells drilled subsequent to adoption of the phosphate-quebracho mud treatment method. The transition period was from 1938 to 1940, during which time the treatment was a combination with the previous treatment of caustic soda, quebracho, soda ash and sodium silicate. Two of the wells drilled during this period have failed, but the major problem developed when the transition was complete and low pH (8.5±) mud was in general use. There is no other factor which corresponds with the inception of casing corrosion so well as the change in the mud treatment program.

The seven samples from Taylor 132 (pipe scale, residual mud cake and five sidewall cores) plus samples of salt water produced from the interval 3427/3625 feet in Gosnell 38 and mud from the Taylor mud reservoir were subjected to bacteriological analysis. The results of these analyses are presented in Table III. The fact that the residual mud cake, the reservoir mud and the salt water gave positive tests within one week indicates that the bacteria were numerous and active. Even the three-week lag on the pipe scale and sidewall core tests is not a sign of low bacterial activity. The usual maximum incubation period in the laboratory which performed this phase of the work is twelve weeks and some samples have tested positive only after six to eight months' incubation.

The mere presence of the sulfate reducers in these samples does not prove that the bacteria are responsible for the corrosion. However, this fact plus all the foregoing substantiating data lead reasonably to the conclusion that anaerobic sulfate-reducing bacteria are the fundamental cause of the corrosion. Furthermore, none of the other theories considered correlates as well with the available data.

## Preventive Measures

Having concluded with a reasonable degree of certainty that sulfate-reducing bacteria are responsible for the casing corrosion, it became possible to concentrate on the development of preventive measures. As indicated in the previous discussion of preventive measures considered, there are two distinct problems, existing wells and future wells.

### *Existing Wells*

The existing wells, of course, present the most difficult problem. Consideration was given first to various types of radiation since it would be practically impossible to change the environment behind the casings by displacing the existing mud with some other fluid. A preliminary investigation was made of the applicability of gamma ray, neutron and ultrasonic radiations, none of which would permanently change the environment. It was found that the energy requirements are so excessive as to render them completely impractical. The difficulty of destroying bacteria without permanently altering their environment lies in the fact that it is necessary to eliminate practically each individual. These bacteria reproduce by fission, so their multiplication in a favorable environment may be very rapid. The possibility of applying large amounts of direct current in an effort to electrolyze the fluid outside the casing, thus raising the pH and, at least temporarily modifying the environmental conditions behind the pipe is still being considered. If this method does not work, the only other possibility lies in the use of one or more of the possible mechanical methods for minimizing the seriousness of the leaks.

### *Future Wells*

The future wells present a somewhat easier problem than the existing wells because the environment behind the casing is subject to some degree of surface control. Having established that the bacteria are the probable cause of the corrosion and that the early wells drilled with moderately high pH muds have not failed, the immediate and obvious approach would be to revert to the use of high pH muds. Before such a step could be recommended it was necessary to conduct experiments from the standpoints of both bacterial activity and present mud technology.

Insofar as the physical properties of the mud are concerned, there was little doubt that high pH muds

**TABLE III**
**Results of Bacteriological Analyses**

| Sample | Description | Sulphate Reducers After | | |
|---|---|---|---|---|
| | | 1 Week | 2 Weeks | 3 Weeks |
| A | Pipe Scale | — | ? | + |
| B | Sidewall core, 2,391′ | — | — | + |
| C | Sidewall core, 2,393′ | — | — | ? |
| D | Sidewall core, 2,395′ | — | — | ? |
| E | Sidewall core, 2,397′ | — | — | ? |
| F | Sidewall core, 2,399′ | — | — | ? |
| G | Residual mud cake | + | + | + |
| H | Water sample, Gosnell 38 | + | + | + |
| I | Taylor reservoir mud | + | + | + |

could be mixed. Muds of this type are widely used in many places. The point in question was whether or not the Dent clay, a native material of relatively poor quality, could be used as a base for the high pH muds. Laboratory tests were made with both the sodium clay and calcium clay varieties of alkaline mud. These tests showed that the Dent clay is a suitable base material and that the high pH muds actually are superior in many ways to the low pH mud previously used. Furthermore, the calcium variety has better heat tolerance than the phosphate-treated mud, an important factor in drilling deep wells. Thus, it was shown that there are no major physical objections to the use of high pH mud.

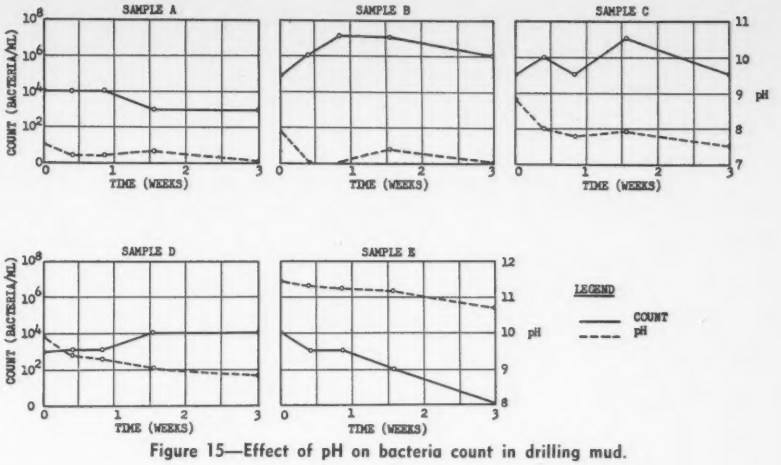


Figure 15—Effect of pH on bacteria count in drilling mud.

It is generally known that bacteria are inactive in aqueous media above about pH 9.[2] However, there was little knowledge about the validity of this limit in the complex colloidal medium of drilling fluid. Therefore, several tests were performed to study bacterial activity in drilling fluid at various pH conditions. For these tests samples of mud were prepared as listed in Table IV.

**TABLE IV**
**Mud Samples for Bacteriological Analyses**

| Sample | Composition | pH as Mixed | pH as Tested |
|---|---|---|---|
| A | Raw Dent mud | 8.1 | 7.5 |
| B | Mud, 0.25#/bbl. caustic, 4#/bbl. quebracho... | 8.8 | 7.8 |
| C | Mud, 0.5#/bbl. caustic, 2.5#/bbl. quebracho... | 9.8 | 8.8 |
| D | Mud, 1.0#/bbl. caustic, 2.0#/bbl. quebracho... | 11.1 | 9.9 |
| E | Mud, 2.0#/bbl. caustic, 2.0#/bbl. quebracho... | 12.4 | 11.0 |

The table shows that the pH readings obtained after receiving the mud samples in the bacteriological laboratory were somewhat lower than those recorded at the time of mixing. This is presumed to be due to the relatively short hydration period given the freshly mixed samples or to a complex reaction between the quebracho and the caustic soda.

The first tests were made to assess the initial bacterial contamination of the samples. This was performed by inoculating culture media with small amounts of the various muds. Briefly, these tests showed that Samples A, B and C exhibited light to moderate activity whereas Samples D and E showed none.

The next and most important tests were made to determine the effect of various pH's on the activity of sulfate-reducing bacteria. To perform this test, fixed quantities of the various muds were inoculated with active sulfate reducers previously cultured from the pipe scale and sidewall cores obtained from Taylor 132. Bacterial activity counts were then made by the serial dilution method. The counts were repeated five times during the succeeding 21 days. The results of these tests then are indicative of the trend of bacterial activity in each mud and are presented graphically in Figure 15.

As shown by the graphs, Sample E, the only sample whose pH was above 9.5 throughout the test, was the only mud in which there was complete cessation of bacterial activity at the end of three weeks. Sample D appeared to have remained almost at equilibrium until the pH dropped to 9.0. When the pH declined the bacterial activity appeared to have increased.

In further experiments, two samples of drilling mud having stabilized pH values of 11.5 and 10.8 were inoculated with sulfate-reducing bacteria. Bacterial activity ceased after incubation for one week in the sample of pH 11.5, and after three weeks in the sample of pH 10.8. That the composition of these mud samples (other than pH) was not inimical to the growth of sulfate-reducing bacteria was established by lowering the pH of the muds to 9 (with diluted sulfuric acid) and successfully culturing the re-inoculated samples. The over-all indication from these tests is that high pH drilling fluids will definitely inhibit bacterial growth.

Having determined that the high pH muds are satisfactory drilling fluids and bacterial activity inhibitors, they are now used in drilling to the casing point in all Shell wells in the Ventura Avenue field. Since the full-string cementing method probably would not add appreciably to the effectiveness of the high pH muds in preventing corrosion, the practice has been discontinued.

Some studies have been made of the effectiveness of bactericides in high pH mud. The tests are presently incomplete, but the initial indications are that the bactericides do not inactivate bacteria as effectively as does a high pH environment. The studies are being continued because the bactericides might have some value in connection with the use of low pH muds. One major difficulty lies in the fact that most of the bactericides are detrimental to the mud properties.

## Conclusions

Extensive efforts to determine the cause of the corrosion by means of statistical studies or surface measurements met with little success. Likewise, the development of preventive measures was characterized more by failures than successes. The only

method which appeared to have practical merit was full-string cementing. The full-string cementing program which was undertaken was believed to have a reasonable chance of effecting a solution to the problem, but it was recognized that the data to support this belief were very tenuous.

The recovery of corroded casing, long thought to be the key to the solution, was effected in December 1949. Study of all phases of the problem since recovery of the casing now permits the conclusion that the activity of anaerobic sulfate-reducing bacteria is responsible for the casing corrosion. Tests have demonstrated that highly alkaline drilling fluid will inactivate the bacteria and this type of mud is now used in all Shell wells in the Ventura Avenue field. Also, full-string cementing has been discontinued as it no longer appears necessary.

The prevention of casing corrosion in the existing wells remains as a difficult, if not impossible, problem. The absence of any preventive measures may make the use of mechanical measures for minimizing the seriousness of the leaks economically attractive.

## Acknowledgment

Appreciation is expressed for the cooperation of several individuals who have contributed materially to the progress of this investigation: Mr. J. E. Gallagher of Shell Oil Company participated in statistical studies and aided in prosecuting the field investigations. Mr. P. J. Raifsnider of Shell Development Company conducted the bacteriological studies. Mr. R. S. Treseder of Shell Development Company participated in developing the program of investigation and in guiding corrosion and diagnostic experiments in the laboratory. Dr. C. E. ZoBell of Scripps Institution of Oceanography advised on bacteriological matters. Mr. G. A. Nelson of Shell Development Company advised on metallurgical matters.

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# Corrosion in the Ammonolysis Of Aliphatic Chlorides*

By R. S. TRESEDER and R. F. MILLER

IN THE DEVELOPMENT of a continuous process for the manufacture of allylamine or methallylamine by the ammonolysis of the corresponding chlorides[1] with liquid ammonia certain severe corrosion problems were encountered. One case involved the reactor and the other the amine recovery system. As these systems were investigated it became apparent that relatively novel corrosion reactions were involved, about which there was very little information in the literature. Therefore, in addition to obtaining the usual information regarding corrosion resistance of various alloys in several pilot plant locations, laboratory study was made of synthetic mixtures comparable to the plant streams in order to identify the essential corrosive components and to learn more about the factors influencing these unusual corrosion reactions.

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## Abstract

Corrosion data are presented relating to a process for manufacture of methallylamine by the high pressure liquid phase ammonolysis of methallyl chloride. Relative corrosion resistance of a number of alloys has been determined for the two most severely corrosive process streams encountered, one involving essentially an anhydrous solution of ammonium chloride in liquid ammonia and the other a mixture containing methallylamine and unreacted aliphatic chloride. The two systems have been found to have similar corrosion characteristics. Study of other combinations of amines and aliphatic chlorides has revealed such combinations to be generally corrosive to carbon steel and other common alloys under moderately high temperature conditions.


### Corrosion in Methallylamine Process

The process developed for manufacture of methallylamine involved contacting methallyl chloride with an excess of ammonia at a temperature of *ca* 90° C and a total pressure of *ca* 850 psig., the reactor products going to an ammonia stripper operating at a reboiler temperature of 130° C; excess caustic soda was introduced with the feed to the stripping column to convert ammonium chloride to ammonia. The stripper bottoms, consisting of an organic phase and a water phase were sent to a recovery system where, by a series of distillations, pure primary methallylamine was obtained as the final product.

Figure 1 shows a flow sheet for the pilot plant, which includes the reaction zone and ammonia stripper, which were the locations of importance from the corrosion viewpoint, but does not include the recovery system. The process stream was found to be severely corrosive to carbon steel in the reaction zone and in the reboiler of the ammonia stripping column. In other locations carbon steel appeared to be a suitable material of construction.

#### *Reaction Zone*

Typical corrosion data obtained from test specimens inserted in a pilot plant reactor are presented in Table I. The rate of corrosion of carbon steel was quite high (*ca* 200 mils/yr). Use of carbon steel equip-

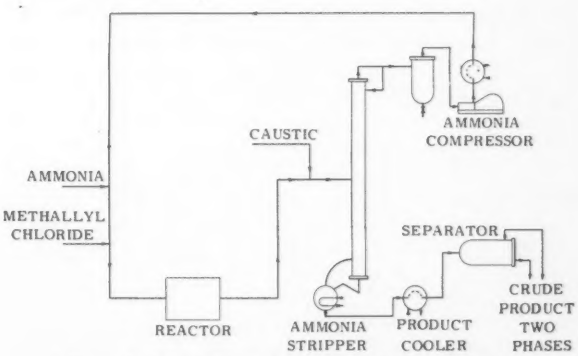


Figure 1—Flow diagram of methallylamine pilot plant.

* A paper presented at the Seventh Annual Conference and Exhibition, National Association of Corrosion Engineers, New York, N. Y., March 13-16, 1951.

ment in this section of the pilot plant led to severe plugging problems from the accumulated corrosion product, which was analyzed and found to correspond to $FeCl_2 \cdot 6NH_3$. Data obtained from specimens of various alloys showed that substantially complete corrosion resistance was obtained only with highly alloyed stainless steels such as type 317 or Worthite, or a molybdenum, nickel, chromium alloy such as Hastelloy C. Nickel and copper alloys in general were subject to severe general corrosion and were no more resistant than carbon steel. The austenitic stainless steels had fairly good resistance to attack, but alloys such as Type 304 or Type 316 were susceptible to occasional severe pitting; this tendency for pitting was confirmed by inspection of Type 304 stainless steel piping in the reactor system. Instances of cracking were observed with stressed specimens of Type 304 and 316 stainless steels and in at least one instance Type 304 stainless steel showed slight intergranular corrosion when exposed without stress following a sensitizing heat treatment such as might occur during welding.

Organic coatings on steel such as baked phenolic enamels and baked furan base enamel were unsatisfactory in this system.

## Corrosive Nature of Ammonium Chloride, Ammonia Solutions

A series of laboratory corrosion tests (Table II) with various synthetic mixtures of compounds present in the process stream in the reaction zone showed that the essential corrosive system consisted of a solution of ammonium chloride in liquid ammonia.

That solutions of certain ammonium salts, including ammonium chloride, in liquid ammonia were corrosive to carbon steel and other common alloys has been reported.[2,3] The explanation offered for the occurrence of corrosion in this anhydrous system is that the liquid ammonia serves as a polar solvent for the ammonium chloride, the latter having strongly acidic properties in this medium. An ammonia solution of ammonium chloride is thus considered analogous to an aqueous solution of hydrochloric acid. The corrosion reaction is presumed to be as follows:

$$2\,NH_4Cl + Fe \longrightarrow FeCl_2 + 2\,NH_3 + H_2$$

The ammoniated salt ($FeCl_2 \cdot 6\,NH_3$) is formed as a sparingly soluble corrosion product. This explanation of the observed corrosion was in agreement with pilot plant inspection data for the reaction system wherein severe corrosion of carbon steel was observed only in those zones where ammonium chloride was present, there being no pronounced corrosion in the individual feed systems nor in the ammonia recycle stream.

Further laboratory test (Table II) indicated that the presence of water in the mixture had no marked effect on the corrosion rate of carbon steel. It was found that arsenic compounds had an inhibiting effect on the corrosive action of ammonium chloride, ammonia solutions on carbon steel. While use of an inhibitor would not be practical for this particular process, the result is interesting in that it adds indirect support for the above conclusions regarding the acidic character of this solution, since arsenic compounds are well-known corrosion inhibitors in aqueous acid systems.

**TABLE I**

**Corrosion Resistance of Various Alloys Under Methallylamine Reactor Conditions**

**Conditions:**

Reactor
Liquid ammonia containing amines, $NH_4Cl$, and organic chlorides plus polymer
0.1x0.5x2.0 in. ground specimens insulated with Teflon in outlet of reactor.
Pressure 850 psig., Temperature, 90 °C., Operating Time, 26 days.

| ALLOY[a] | CORROSION RATE, mils/yr | |
|---|---|---|
| | General | Max. Localized |
| Carbon steel | 240 | >800 |
| Hastelloy C, wrought | 0.07 | Nil |
| Worthite, cast | 0.2 | Nil |
| Durimet T, cast | 0.7 | ... |
| Type 317 stainless steel | 0.1 | Nil |
| Type 316 stainless steel | 0.8 | 100 |
| Type 304 stainless steel | 2 | 130 |
| Type 347 stainless steel | 7 | 100 |
| Hastelloy B, wrought | 4 | 16 |
| Inconel | 6 | 16 |

Previous tests had shown the following alloys to be severely corroded: 50-500 mil/yr.: Type 410 stainless steel, Nickel, Lead, Monel. >1600 mil/yr.: Copper, Aluminum 2S.

[a] Nominal compositions listed in Table VII.

**TABLE II**

**Corrosion of Carbon Steel in Liquid Ammonia Solutions**

**Conditions:**

250-ml. stainless steel pressure vessel; 100 g. solution of indicated composition.
Duplicate 0.1x0.5x2.0 in. ground specimens of carbon steel in each test; specimens totally immersed.
Pressure ($NH_3$), ca. 500 psig. 80° C. No agitation.

| Solution Composition, %w | | | Duration, Days | Corrosion Rate, mils/yr |
|---|---|---|---|---|
| $NH_3$ | $NH_4Cl$ | Other | | |
| 88[a] | 5[a] | [a] | 2 | 70, 100 |
| 90 | 10 | ..... | 1 | 80, 80 |
| 90 | 10 | ..... | 3 | 70, 80 |
| 90 | 0 | 10-NaCl | 2 | 10, 10 |
| 79 | 12 | 9-MAA[b] | 1 | 90, 100 |
| 59 | 9 | 7-MAA; 25-$H_2O$ | 1 | 50, 70 |
| 89 | 10 | 1.0-$As_2O_3$ | 1 | 5, 7[c] |

[a] Sample from pilot plant reactor; contained prim. methallylamine secondary methallylamine, polymers, and organic chlorides.
[b] MAA=primary methallylamine.
[c] Slight pitting.

**TABLE III**

**Corrosion Resistance of Various Alloys in the Reboiler of the Ammonia Stripping Column**

**Conditions:**

Reboiler of ammonia stripping column.
Water containing amines, NaCl, 2% NaOH, organic chlorides plus polymer. Present as two phases, organic (upper) phase being small fraction of total.
0.1x0.5x2.0 in. ground specimens insulated with Teflon. Immersed in liquid in kettle.
Temperature 125 to 130° C.

| ALLOY | CORROSION RATE, Mils/yr | | | |
|---|---|---|---|---|
| | 41 Day Test | | 7 Day Test | |
| | General | Max. Localized | General | Max. Localized |
| Carbon steel | 2 | 18 | 35 | .... |
| Hastelloy C | 0.1 | .... | .... | .... |
| Worthite, cast | 0.2 | .... | .... | .... |
| Type 317 stainless steel | 0.3 | .... | .... | .... |
| Type 316 stainless steel | 0.3 | .... | .... | .... |
| Type 304 stainless steel | 0.4 | 9 | .... | .... |
| Type 347 stainless steel | 0.6 | 19 | .... | .... |
| Inconel | 0.2 | .... | 0.3 | 92 |
| Hastelloy B | 2 | .... | .... | .... |
| Nickel | 1 | .... | 3 | 140 |
| Monel | 1 | 23 | 4 | 100 |
| Copper | .... | .... | 42 | 300 |

### *Ammonia Stripping Column*

Severe corrosion of carbon steel heating tubes was observed in the reboiler of the ammonia stripping column. This effect was unexpected in that the proc-

**TABLE IV**

**Corrosion of Carbon Steel by Mixtures of Organic Chlorides and Amines as Encountered in Methallylamine Process**

**Conditions:**
0.6 in. diam. x 8.0 in. long sealed Pyrex tube.
8 ml. of indicated mixture of amine and organic chloride (1:1 mole ratio unless otherwise noted).
Two carbon steel specimens, 0.1x0.25x2.0 in. ground surface, one in vapor phase and one in liquid phase (latter only reported).
Tube evacuated before sealing off. 110° C. No agitation. 1 day.

| Amine[a] | Chloride[a] | Special Conditions | CORROSION RATE, mils/yr | |
|---|---|---|---|---|
| | | | No $H_2O$ Added | 10% $H_2O$ Added |
| None | AC | ..... | 8 | 41 |
| None | MAC | ..... | 4 | 3 |
| None | ICC | ..... | 3 | 1 |
| AA | None | ..... | 8 | 3 |
| AA | AC | ..... | 170 | 300 |
| SAA | None | ..... | 4 | 3 |
| SAA | AC | ..... | 43 | 830 |
| MAA | None | ..... | 13 | 19 |
| MAA | MAC | ..... | 490 | 27 |
| MAA | ICC | ..... | 18 | 11 |
| SMAA | None | ..... | ..... | 7 |
| SMAA | MAC | ..... | 240 | 28 |
| SMAA | MAC | 0.1 mole ratio SMAA/MAC | 440 | ..... |
| SMAA | MAC | 4.4 mole ratio SMAA/MAC | 100 | ..... |
| SMAA | MAC | 150° C. | 290 | ..... |
| SMAA | ICC | ..... | 32 | 22 |
| SMAA | ICC | 0.1 mole ratio SMAA/ICC | 94 | ..... |
| SMAA | ICC | 4.4 mole ratio SMAA/ICC | 1 | ..... |
| SMAA | ICC | 150° C. | 44 | 1 |
| Sample of upper layer from ammonia stripper bottoms[b] | | 100° C. | 4 | ..... |
| " " " | | 140° C. | 3 | ..... |
| " " " | | 190° C. | 150 | ..... |

[a] Materials used were ca 98% pure and were dried to 0.1% $H_2O$ with exception of prim. methallylamine which contained 4% $H_2O$.
AA=prim. allylamine
SAA=sec. allylamine
SMAA=sec. methallylamine
MAA=prim. methallylamine
AC=allyl chloride
MAC=methallyl chloride
ICC=isocrotyl chloride

[b] Typical analysis:

| | |
|---|---|
| Amines | 71% |
| Organic chlorides | 12 |
| High boiling materials | 10 |
| $H_2O$ | 1–7 |

**TABLE V**

**Corrosion by Mixtures of Isopropyl Chloride and Organic Nitrogen Compounds**

**Conditions:**
0.6 in diam. x 8.0 in. long Pyrex tube
10 ml. of isopropyl chloride containing indicated additive
Single carbon steel specimen, 0.1x0.25x2.0 in., ground surface, totally immersed
Tube evacuated before sealing off. No agitation. Duration, 1 day

| Nitrogen Compound Added | %w | Temp., °C. | Corrosion Rate, mils/yr. |
|---|---|---|---|
| None | .... | 102 | 8 |
| None | .... | 192 | 42 |
| Acetonitrile | 4 | 102 | 12 |
| Acetonitrile | 4 | 155 | 256 |
| Acetonitrile | 4 | 192 | 1150 |
| Tetradecane nitrile | 4 | 192 | 400 |
| Pyridine | 4 | 192 | 720 |
| Tributylamine | 1 | 182 | 135 |
| N,N'dimethylaniline | 1 | 182 | 320 |

[a] 4 day test.

**TABLE VI**

**Corrosion Resistance of Various Alloys to Acetonitrile, Isopropyl Chloride Mixture at High Temperature**

**Conditions:**
As in Table V. All tests made with 4% solution of acetonitrile in isopropyl chloride. 1 day at 192° C. Duplicate tests.

| ALLOY | Corrosion Rate, mils/yr | |
|---|---|---|
| Carbon steel | 540, | 1150 |
| Hastelloy B | 4, | 6 |
| Nickel | 4, | 5 |
| Monel | 6, | 65 |
| 70-30 Cu-Ni | 118, | 410 |
| Copper | 116, | 155 |
| Type 304 stainless steel | 510, | 680 |
| Type 316 stainless steel | 530, | 1000 |

ess stream at this point consisted of a definitely alkaline water phase plus a lesser amount of organic layer which was predominately methallylamine. Typical corrosion data obtained from specimens placed in the reboiler of the ammonia stripping column are given in Table III. While the corrosion rates measured with carbon steel specimens under these conditions were erratic, a number of moderately high values (*ca* 50 mils per year) were obtained, the corrosion tending to be of a localized nature. More severe corrosion of the heating tubes would be expected than of the specimens owing to the higher surface temperatures of the heating tubes.

Corrosion resistance of various alloys followed a pattern similar to that noted above for the reactor location although the individual corrosion rate values were somewhat lower. The austenitic stainless steels and related alloys showed the best resistance to attack; however, with Type 304 stainless steel there was a tendency to pitting. In a limited number of tests there was no observed tendency for intergranular corrosion or stress corrosion cracking with the stainless steels. Type 304 stainless steel heating tubes used as replacements for the corroded carbon steel tubes in the kettle showed low general corrosion with definite pitting. It would appear that molybdenum bearing stainless steels would be required for maximum corrosion resistance in this location. Inspection of pilot plant equipment indicated that the severe corrosion conditions were confined to the section of the ammonia stripping column below the feed entry and did not extend beyond the heat exchanger employed to cool the bottoms product.

## Corrosion by Mixtures of Amines and Organic Chlorides

There was no immediately obvious explanation for the corrosion observed in the ammonia stripper reboiler. An excess of caustic presumably was present at all times; and the temperature conditions were not considered severe enough to explain the effects on the basis of caustic corrosion of steel. Exploratory tests indicated that the corrosion was occurring in the organic phase present in the process stream and that the active agent was probably unreacted organic chlorides. This was confirmed by results from a series of tests (Table IV) which showed that the corrosive effects were a general characteristic of mixtures of amines and organic chlorides at moderately high temperatures. Although in some instances there was slight corrosion with the organic chlorides alone, the combination of amine and chloride appeared to be required to produce severe corrosion. A number of combinations of amines and chlorides were tested including the various compounds that might be present in the process stream. No marked effects of type of amines (primary or secondary, allyl- or methallyl-) were noted. Allyl and methallyl chlorides gave somewhat more corrosive mixtures with amines than did isocrotyl chloride. As a general rule the corrosiveness of the various mixtures appeared to increase with increasing mol ratio of chloride to amine. The addition of water had no consistent

effect. There was a definite accelerating effect due to temperature. With an actual sample of the organic layer from the ammonia stripper bottoms stream the corrosion rate of carbon steel was found to increase extremely rapidly above 140° C. With some of the synthetic mixtures pronounced corrosion was observed as low as 110° C.

The corrosion mechanism suggested to explain these effects is related to that given above for the liquid ammonia, ammonium chloride system. The amine in this case serves as the polar solvent and at high temperature reacts with the organic chloride present to provide a corrosive agent in the form of an amine hydrochloride analogous to ammonium chloride. The reactions involved are considered to be:

$$R_1NH_2 + R_2Cl \longrightarrow R_1R_2NH \cdot HCl \quad (1$$

$$2R_1R_2NH \cdot HCl + Fe \longrightarrow FeCl_2 + 2R_1R_2NH + H_2 \quad (2$$

That corrosion occurred in the plant location where an excess of caustic was present must be attributed to the lack of complete mixing of the two liquid phases.

*Methallylamine Recovery System*

No pilot plant corrosion data are available for the methallylamine recovery system. However, laboratory tests with a number of synthetic mixtures simulating various possible process streams indicated that corrosion would not be a serious problem despite the occurrence in a few locations of relatively high chloride concentrations. This was attributed to the lower temperatures (100° C maximum) employed in this system.

*Corrosion in the Allylamine Process*

A limited amount of data obtained during production of allylamine using the same pilot plant facilities and substantially the same process conditions were in substantial agreement with the data obtained for the methallylamine process.

### Corrosion by Other Combinations of Nitrogen Compounds and Organic Chlorides

The corrosion effects obtained with amine, chloride mixtures in the methallylamine process were found to be a general characteristic of combinations of organic chlorides with amines or certain other nitrogen compounds at moderately high temperatures. In the laboratory corrosion tests summarized in Table V severe corrosion of carbon steel occurred with mixtures containing either an aliphatic nitrile (acetonitrile), a tertiary aliphatic amine (tributylamine), an aromatic amine (dimethylaniline), or a heterocyclic nitrogen base (pyridine). For one of these systems i.e., acetonitrile and isopropyl chloride, corrosion data were obtained for several alloys (Table VI). Results showed nickel and related alloys (Monel and Hastelloy B) to have appreciably better corrosion resistance than the austenitic stainless steels.

**TABLE VII**
**Composition of Alloys Employed in Corrosion Tests**

| ALLOY | Nominal Compositions of Alloys Employed in Corrosion Tests |
|---|---|
| Carbon steel | 0.32 C; Fe |
| Type 304 stainless steel | 0.08 max. C; 8-11 Ni; 18-20 Cr; Fe |
| Type 316 stainless steel | 0.1 max. C; 2-3 Mo; 10-14 Ni; 16-18 Cr; Fe |
| Type 317 stainless steel | 0.1 max. C; 3-4 Mo; 11-14 Ni; 18-20 Cr; Fe |
| Type 347 stainless steel | 0.08 max. C; Cb 10xC min.; 9-12 Ni; 17-19 Cr; Fe |
| Worthite | 20 Cr; 24 Ni; 3 Mo; 4 Si; 2 Cu; Fe |
| Durimet T | 0.07 max. C; 2 Mo; 1 Cu; 1 Si; 19 Cr; 22Ni; Fe |
| Copper | 99.9 Cu |
| Copper Nickel | 70 Cu; 30 Ni |
| Monel | 67 Ni; 30 Cu; 1.4 Fe |
| Nickel | 99.4 Ni |
| Inconel | 79.5 Ni; 13 Cr; 6.5 Fe; 0.08 C |
| Hastelloy B | 26-30 Mo; 4-7 Fe; 0.12 max. C; Ni |
| Hastelloy C | 16-18 Mo; 16-18 Cr; 4-5 W; 5-7 Fe; 0.15 max. C; Ni |

This result is opposed to that obtained in the methallylamine process, but it is thought that this variation might be associated with the differences in such factors as temperature and concentrations of the essential components.

### Conclusions

It has been shown that in the ammonolysis of aliphatic chlorides two corrosive systems could be encountered, 1) solutions of ammonium chloride in liquid ammonia in the reaction zone, and 2) solutions of unreacted organic chloride in amine in the amine recovery system. Under methallylamine process conditions highly alloyed stainless steels, e.g. Worthite, or nickel-molybdenum-chromium alloys, e.g. Hastelloy C, were required for the reactor location, and molybdenum bearing austenitic stainless steels for the ammonia stripper reboiler.

Of particular importance was the recognition of the potentially corrosive nature of solutions of ammonium chloride in liquid ammonia and of mixtures of organic chlorides and amines or nitriles. In both cases presence of water was found to be unimportant as a corrosive factor; however, temperature was a strongly accelerating factor, the critical temperature varying among individual combinations, but being of the order of 100° C with the amine, organic chloride system. There were indications of sufficient variations in corrosion behavior among the various combinations tested to suggest that such systems should be investigated individually before finally selecting materials of construction.

### Acknowledgment

The authors acknowledge the cooperation of their colleagues in Shell Development Company, especially the guidance of A. Wachter and the contribution of G. G. Eldredge.

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# The Corrosion of Titanium in Acids*

## *The Rate of Dissolution in Sulfuric, Hydrochloric, Hydrobromic and Hydroiodic Acids*

By M. E. STRAUMANIS and P. C. CHEN

THE DATA ON dissolution of titanium in various reagents can be found only in recent literature. These data, as remarked by Kroll[1] concern mostly the impure brittle metal.[2] Further, all the papers published are of qualitative nature except two[3,4] which were published while the present research was under way. Some quantitative data concerning the rate of dissolution can be found also in the papers of Fontana,[5] Dean and co-workers[6] and Gee.[7] There are no papers dealing with the mechanism of dissolution.

In view of this and because the approach in this research is quite different from that indicated in the papers of Gee[3] and Hutchison,[4] and because titanium itself as a new corrosion-resistant material is of high importance, the publication of the present investigation is justified.

### Reaction of Titanium with Sulfuric and Halogen Acids

*Sulfuric Acid Reaction*

The minimum concentration of sulfuric acid that reacted with high purity titanium samples was 2 N (over 9 percent). 1 N acid showed no sign of reaction even in 10 days. The reaction with the 2 N acid, however, was not appreciable and the sample was only slightly dulled after the reaction. Boiling the 2 N acid accelerated the reaction somewhat.

It is not quite clear what product results when titanium dissolves in dilute sulfuric acid. Glatzel[8] believes that $Ti_2(SO_4)_3$ is formed, while Stähler and Wirthwein think that $TiSO_4$ results.[9] It seems to be that Glatzel is right for the following reasons:

1. Titanium (II) sulfate ($TiSO_4$) must be like $TiCl_2$ a very reactive compound and, therefore, could not form during dissolution of titanium and

2. It was shown quantitatively that during the dissolution of the mentioned metal in hydrofluoric acid only the trifluoride is formed.[10]

So the reaction of dissolution should be:

$$2\,Ti + 3H_2SO_4 \rightarrow Ti_2(SO_4)_3 + 3H_2 \qquad (1$$

$$\text{or } Ti \rightarrow Ti^{2+} + 3e \qquad (2$$

Titanium (IV) sulfate is never formed directly during this reaction. But it can appear later due to the oxidation of titanium (III) sulfate, if the dissolution occurs in the presence of air or other oxidizing agents:

$$2\,Ti_2(SO_4)_3 + 2\,H_2SO_4 + O_2 \rightarrow 4\,Ti(SO_4)_2 + 2H_2O \qquad (3$$

$$\text{or } 4\,Ti^{3+} + 4H^+ + O_2 \rightarrow 4\,Ti^{4+} + 2\,H_2O \qquad (4$$

Concentrated acid (about 36 N or 96 percent) reacted readily with copious liberation of small hydrogen gas bubbles. A series of acids of intermediate concentrations including 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32 and 34 N, were all found to react with the titanium samples. The color of the solution changed from dark violet, shaded into bright violet, and finally turned to blue as the concentration of the acid increased.

*Hydrofluoric Acid Reaction*

The most active among the halogen acids was hydrofluoric acid. The rate of the reaction was higher than that of sulfuric acid. It was shown that during the dissolution only the reaction (2 occurred.[10] The titanium samples reacted with almost all concentrations of the hydrofluoric acid. With concentrated acid (52 percent) the reaction was very violent and intense heat was evolved. The solutions became instantaneously dark colored. Solutions resulting from the reaction with dilute hydrofluoric acid were colored greenish yellow. Standing in air (oxidation) they turned to brownish yellow.

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## Abstract

It can be shown that the dissolution of titanium in sulfuric, hydrochloric, hydrobromic and hydroiodic acids must proceed according to the reaction $Ti^0 \rightarrow Ti^{3+} + 3e$, exactly as when titanium dissolves in hydrofluoric acid. The rate of dissolution of Bureau of Mines titanium in sulfuric and hydrochloric acids below 2 N is extremely low. The dissolution rate is still lower in hydrobromic acid of all concentrations. Hydroiodic acid does not react at all with purest titanium. Its resistivity can be explained by the formation of protective layers, which are easily dissolved by hydrofluoric acid. Therefore, small amounts of ammonium fluoride, added to the above mentioned acids accelerate greatly the rate of dissolution of titanium even in hydroiodic acid. The presence of protective films on the surface of titanium can be demonstrated by potential and current measurements. The potential of titanium in sulfuric and hydrochloric acids becomes less noble (more anodic) in time, approaching a limiting potential. It also becomes less noble with increasing concentration of the acid. The potential of titanium is +0.26 volt in 1 N, and —0.353 and —0.342 volt in 6 N sulfuric or hydrochloric acid respectively, while in hydrofluoric acid it is —0.77 volt. Hence, titanium does not displace noble metals from their salt solutions until hydrofluoric acid or soluble fluorides are added to the above mentioned acids. The potential of titanium becomes more negative with the widening of the pores of the films. This, in turn, depends on the nature of the film and solvent. The film on titanium shows the property of selfregeneration.

The rate of dissolution of Bureau of Mines titanium in sulfuric acid stronger than 2 N increases with the concentration. The metal shows a tendency for passivation after a time lapse. Remington Arms titanium does not possess this property. The rate of dissolution of titanium is affected by impurities. It can be shown that the behavior of this metal in acids can be explained by the concept of local cells in connection with the presence of protective films on the surface of titanium.


*Hydrochloric Acid Reaction*

Dilute hydrochloric acid (2 N, over 7 percent) reacted only very slowly with titanium. 1 N acid showed no reaction with the metal at room temperature. Concentrated acid (over 38 percent, or 12.2 N) acted readily, as well as the acid of other concentrations. After the reaction all solutions showed a violet color, the deepness of which was approximately proportional to their concentration. Samples removed from the concentrated acid appeared spongy under the microscope and were embrittled. The dissolution reaction must be in all cases like that in sulfuric acid (eq. (2), because it was shown by Ruff and Neumann[11] that the titanium (II) chloride, the formation of which is possible, is a very active compound which decomposes water immediately liberating hydrogen. And since the formation of titanium (IV) chloride was not observed, the only possible reaction remaining is reaction (2.

*Hydrobromic Acid Reaction*

No appreciable reaction was observed either with cold or boiling hydrobromic acid of a concentration of 41 percent. However, the sample after boiling and standing for one week gave a solution which appeared light violet in color.

*Hydroiodic Acid Reaction*

Hydroiodic acid of 10 percent concentration yielded no reaction either at room or at boiling temperature.

Thus, the reaction of titanium with the halogen acids decreases rapidly with the increasing atomic weight of the halogen in the acid.

### Titanium Used

For the determination of the rates of dissolution, titanium obtained from two sources was used. These sources were U. S. Bureau of Mines (nominal purity over 99.1 percent) and Remington Arms (over 99 percent); some samples of less pure titanium were sintered by the Bureau of Mines. The purity of the samples is given according to the data of the current literature.[4,12] The Bureau of Mines sample measured 0.45 mm thick as received in the form of rolled strips with a bright surface. The Remington Arms titanium was in the form of rolled sheet 1.6 mm in thickness. It was subsequently cold rolled to 0.5 mm with the 2-inch laboratory roll. The sintered sample was in a form of sheet 1.5 mm thick and was rolled down with the same roll.

### Experimental Arrangement and Procedure

The rate of dissolution was determined from loss in weight. Titanium for these determinations came from the two sources mentioned. The size of all specimens measured 1 by 2 cm. They first were made a little over size and then filed to exact size. The four corners were rounded off slightly in order to avoid the sharp corner effect when exposed to the acid. A small hole 1 mm in diameter drilled near one corner of the specimens was used to suspend them in the acid solutions on fine glass hooks. Thus the specimens (3 or 4 in one vessel) were suspended in the acid solution without touching any solid except the fine glass hook. (Figure 1.)

The sulfuric acid was of chemically pure grade. Concentration of the acid was checked by titration

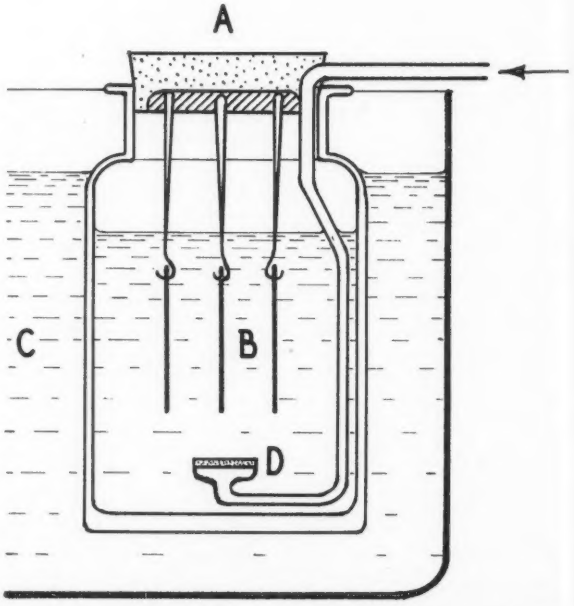


**Figure 1—Arrangement for dissolution tests of titanium in sulfuric acid. A—vessel for dissolution containing 110 ml of acid. B—titanium samples. C—thermostat at 25 degrees plus or minus 0.05 degrees. The thermoregulator, heater, cooling coil and stirrer are not shown. D—fritted glass gas dispersing tube (aerator).**

with standard sodium carbonate solution and was within the range of ±0.005 N of the given normality.

Six reaction vessels were submerged in the water of the thermostat. A cooling coil was used when the room temperature exceeded 25° C.

The samples were cleaned with No. 00 emery paper, rinsed first with distilled water, then with alcohol, dried in a stream of warm air, and weighed. Then they were hung on the glass hooks (Figure 1) and lowered into the acid of the bottle A. Since the rate of dissolution was very slow, a stirrer and a hole for escaping hydrogen were not provided. After a number of hours, usually 24, the samples were taken out of the acid to be rinsed with distilled water and alcohol. Then the samples were dried in a stream of warm air and weighed. The rate of dissolution (V) was calculated by the expression

$$V = \frac{\text{loss in weight}}{\text{area x time}} \text{ in mg/cm}^2 \text{ hour} \qquad (5$$

For each sample the rate was calculated in this way. However, the average rate of dissolution for a given number of samples was obtained by dividing the sum of their loss in weight by the sum of the exposed area times the hours elapsed.

### The Rate of Dissolution of Bureau of Mines Titanium

The samples were immersed in four different concentrations of sulfuric acid (3, 4, 5 and 6 N). Three samples were treated in each concentration. The duration of the experiments was from 500 to 900 hours.

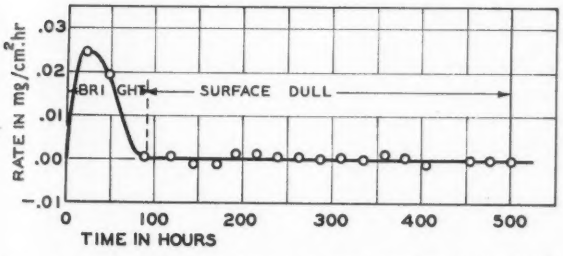


Figure 2—Corrosion rates of Bureau of Mines titanium in 3 N $H_2SO_4$ versus time. Mean values of three tests.

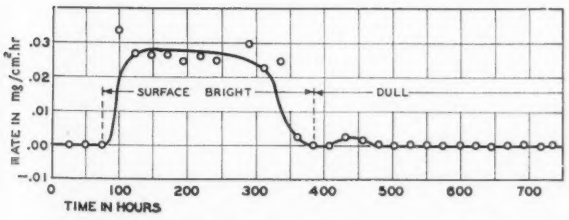


Figure 3—Corrosion rates of Bureau of Mines titanium in 4 N $H_2SO_4$ versus time. Mean values of three tests.

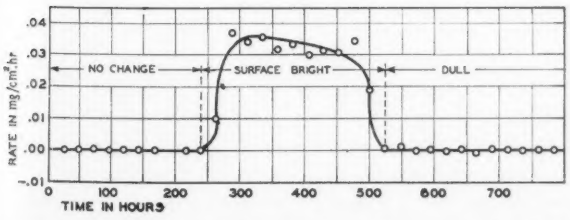


Figure 4—Corrosion rates of Bureau of Mines titanium in 5 N sulfuric acid. Mean values of three tests.

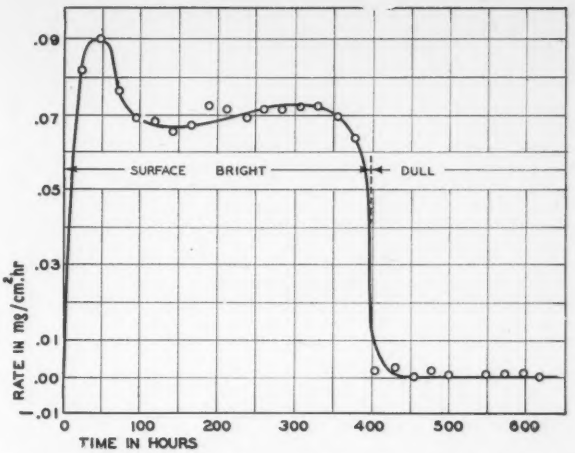


Figure 5—Corrosion rates of Bureau of Mines titanium in 6 N sulfuric acid. Mean values of three tests.

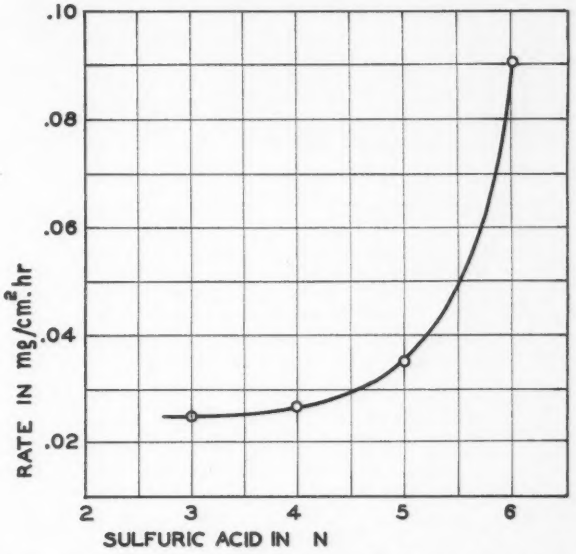


Figure 6—Maximum rate of dissolution of Ti (Bureau of Mines) in various concentrations of $H_2SO_4$.

The corrosion or dissolution rates obtained in 3 N sulfuric acid are plotted against time (hr.) in Figure 2. The Figure shows that the maximum rate occurred at the 23rd hour after immersion and went down almost to the zero rate at the 90th hour. The surface of the samples during this dissolution period remained bright. After the rate slowed down nearly to zero, the samples began to show a dulled surface, increasingly violet in color in the course of time. This indicated the formation of a protective film on the surface of the samples.

The results obtained with three other samples in 4 N sulfuric acid are shown in Figure 3. The reaction started after 75 hours (induction period), the rate increasing to about 0.03 mg/cm² hr, which was maintained almost until the 360th hour and then decreased

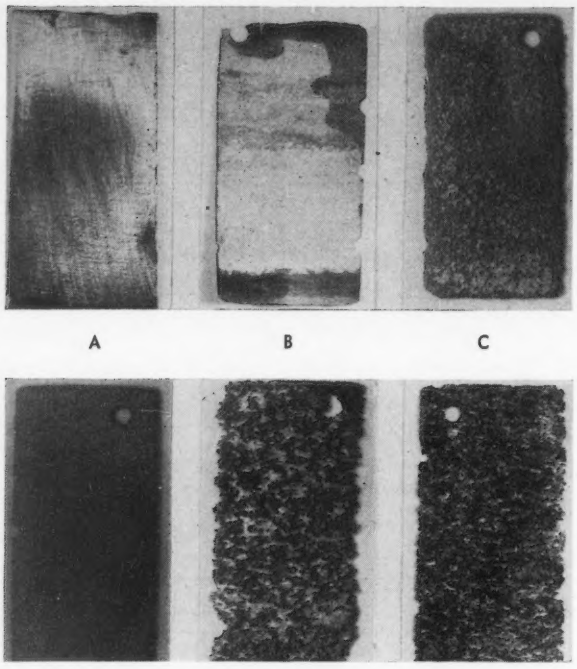


**Figure 7—Samples of titanium after corrosion in 6 N sulfuric acid.**

**A—the original surface.**
**B—Bureau of Mines titanium after 333 hours.**
**C—Remington Arms titanium, cold rolled, after 1116 hours.**
**D—Remington Arms titanium, heated, after 1116 hours.**
**E—sintered titanium, cold rolled, after 143 hours.**
**F—sintered titanium, heated, after 310 hours.**

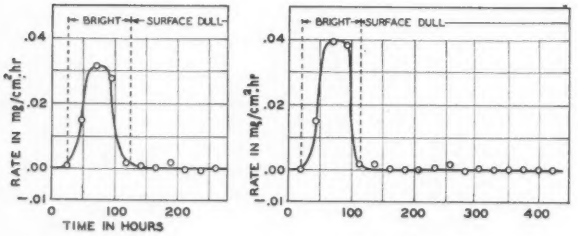


**Figure 8** **Figure 9**

**Effect of aeration on titanium passivated in 3 N sulfuric acid (Figure 2) and 5N acid (Figure 4).**

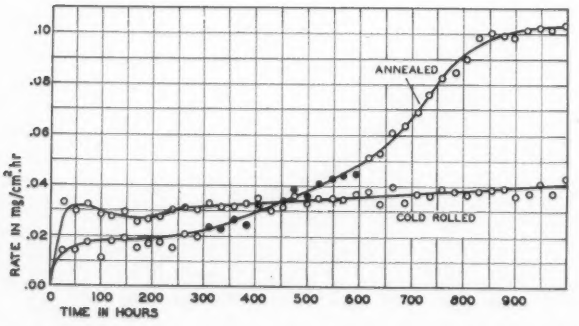


**Figure 10—Rate of dissolution of Remington Arms titanium in 6 N sulfuric acid.**

rapidly. There was no change in surface appearance during the induction period. During the period of dissolution, the surface remained bright, but as soon as the rate decreased the surface of the samples became dull, increasingly violet in color as time elapsed.

Results of the study of the dissolution of titanium in 5 and 6 N sulfuric acid are shown in the Figures 4 and 5. The runs proceed in the same manner as already described. After 400 or 500 hours the samples passivated completely.

When the maximum rates of dissolution in different concentrations are plotted versus concentration of the acid a curve is obtained as shown in Figure 6.

The corrosion rate of titanium increases gently when dissolving in 3 and 5 N, but rapidly in 5 to 6 N acid. The corroded samples are shown in Figure 7.

All these runs were made in the presence of air. Of course, during the dissolution of the titanium the air was partly replaced by hydrogen. It was, therefore, of importance to know how the corrosion would proceed when the hydrogen was removed from the solution as completely as possible, especially in the case of samples the rate of which in the previous runs went down to zero.

The arrangement used for this purpose was made by inserting a glass aerator into the glass bottle, as shown in Figure 1. When compressed air passed through the dense fritted glass gas dispersing tube, a stream of extremely finely divided air bubbles was introduced into the acid so that the solution was saturated with air.

Passivated samples from 3 N, and 5 N acid were studied under the aeration effect. The procedure consisted of introducing the aerator into the same bottle of the same reagent, which had been used for the study of dissolution rate on the passivated samples and recording the new change in the rate, if any, during the passage of air. As shown in the Figures 8 and 9, no appreciable change in weight was noticed in the first 24 hours after the air was blown in. After 48 hours loss in weight resumed and the surface of the sample became bright again. The maximum rate of dissolution was in the vicinity of 0.03 resp. 0.04 mg/cm² hr. (Figures 8 and 9)

When 100 to 120 hours had elapsed, the samples became passive once more, resuming the dull and colored surface. There was no difference in the behavior of the samples whether they were directly in the stream of fine air bubbles or outside of it.

So, three steps could be clearly distinguished in the process of dissolution of Bureau of Mines titanium in sulfuric acid: the induction period, the period of maximum rate, and the period of passivation. If the passive sample was placed in sulfuric acid through which passed an air stream, generally there occurred at first a breakdown of the possibly weak protective film on the surface of the sample formed in the acid rich in hydrogen. Then, after a period of dissolution the passivation started again. However, this dissolution period was shorter, indicating that the protective film subsequently formed was more stable than the original.

### The Rate of Dissolution of Remington Arms Titanium

It was important to know whether other titanium specimens, probably containing impurities, would react in the same way. For this purpose Remington Arms and sintered titanium were chosen.

Four samples were prepared from the cold rolled sheet (0.5 mm) of Remington Arms titanium. Two received a heat treatment at 900° C in a vacuum furnace for one hour and then they were slowly cooled to room temperature. The surface treatment and all other conditions of the runs were the same as already described. However, the rates of dissolution were determined only in 6 N sulfuric acid. Results are summarized in Figure 10. There was no visible film formation on the surface of either heated or cold rolled samples. Dissolution of the cold rolled samples during the first 24 hours was at a rate near 0.03 mg/cm² hr and this increased slowly up to 0.04 toward the end of the 1000-hour period. On the other hand, the heated samples started at a lower rate which increased gradually in 1000 hours up to 0.1 mg/cm² hr (surface of the samples, see Figure 7). Gee and his co-workers also reported a similar phenomenon concerning the corrosion rate of heat-treated titanium in sulfuric acid.[3] However, they observed this behavior only in sulfuric acid of higher concentration (above 40 percent), in a comparatively short period (144 hours) and with aeration in the acid.

### The Rate of Dissolution of the Sintered Sample

Four additional samples were made from titanium sintered by the Bureau of Mines. Two of them were heated in vacuum (description above) and two cold rolled. 6 N sulfuric acid was used for the runs. The results plotted with the rate of dissolution versus time are shown in Figure 11, the surfaces of the samples after corrosion in Figure 7.

The experiments were stopped after 200 or 300 hours because the samples were corroded so badly (see Figure 7) that no further observation could be made on them.

### Comparison of the Rate of Dissolution of Titanium From Different Sources in 6 N Acid

The three different varieties of titanium were studied separately in 6 N sulfuric acid under the same conditions. Only cold rolled samples were used. Figure 12 shows that the Bureau of Mines titanium exhibited a maximum rate of 0.09 mg/cm² hr at 50 hours and was passivated after 400 hours. The rate of corrosion of Remington Arms titanium increased gradually to about 0.04 mg/cm² hr toward the end of the 1000 hours of corrosion, showing no signs of passivation. The impure sintered titanium sample corroded rapidly, reaching a rate of 0.75 mg/cm² hr in 143 hours, then the rate decreased because of formation of holes in the sample. Therefore, no reliable observation could be made.

From this comparison it can be seen clearly that the three samples behaved quite differently. It is highly probable that this can be attributed to the presence of varying impurities in the different samples. Of particular importance seem to be the impurities present in the Bureau of Mines samples, causing the formation of protective films on the metal surface after a time lapse.

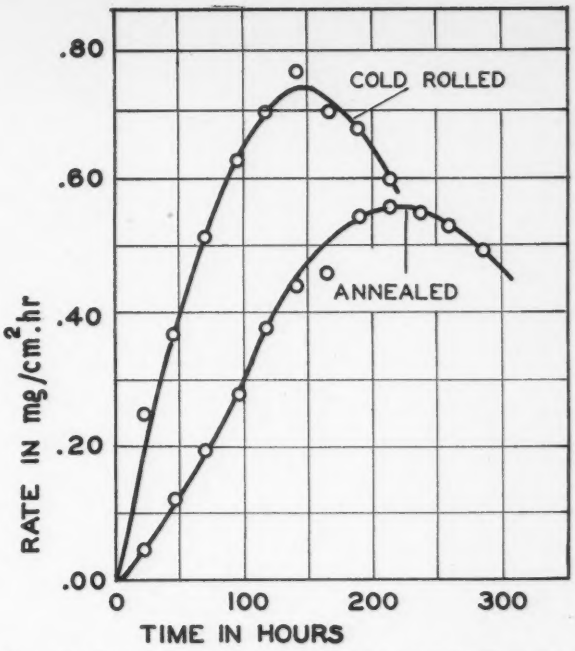


Figure 11—Rate of dissolution of sintered titanium in 6 N sulfuric acid.

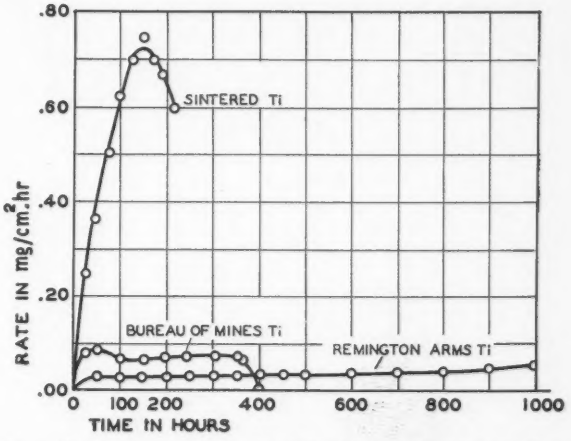


Figure 12—Comparison of the rate of dissolution of titanium from three different sources in 6 N sulfuric acid.

In order to be able to say more about the mechanism of the corrosion process, potential and current density measurements were made with titanium in sulfuric and for comparison, also in hydrochloric acid.

### The Potential of Titanium in Sulfuric and Hydrochloric Acids

According to Evans the measurement of the potential of a corroding metal often gives much information regarding the corrosion process.[13] For these measurements a titanium electrode was used, as shown in Figure 13a. Since only one side of the

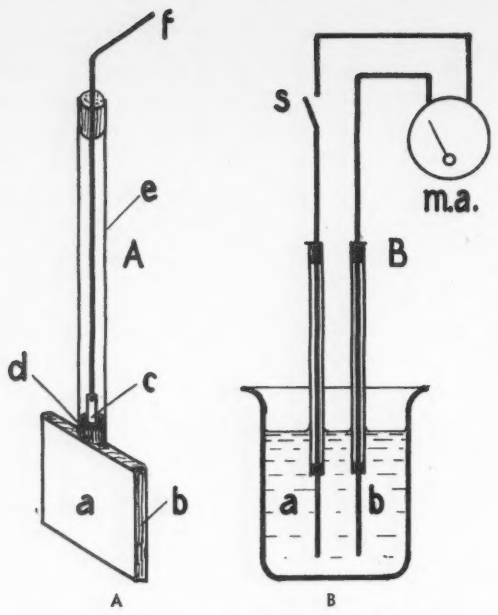


Figure 13 A—Titanium electrode. a—titanium surface (2 x 2 cm). b—coating. c—connection joint. d—sealing (with de Khotinsky cement). e—insulating glass tube. f—copper wire.

Figure 13 B—Setup for measuring the current produced by the titanium electrode in acids. a—titanium electrode. b—platinum electrode (2 x 2 cm). m.a.—milliammeter. s—switch.

electrode was available for the determinations of potential, the other side and edges were covered with plastic cement. The whole setup consisted of the cell

$$Ti \parallel \text{acid} \mid 1\ N\ KCl \mid 1\ N\ KCl, Hg_2Cl_2 \parallel Hg$$

the EMF of which was measured by a potentiometer. Then the potential of the normal calomel cell (0.280 volt at 25°) was subtracted in order to reduce the potential of titanium to the hydrogen scale.

The fine tip of the capillary tube which made the connection with the calomel electrode was pressed against the titanium surface as closely as possible. If the capillary occasionally was clogged by a hydrogen bubble, it was squeezed out easily by a simple device.

The surface of the electrode was cleaned with No. 00 emery paper. However, when the electrode was changed from the acid of lower concentration to that of higher, no such cleaning process was used, except that it was rinsed once with the acid of higher concentration.

The potential was determined in sulfuric acid of the following concentrations: 1, 2, 3, 4, 5, 6, 8, 9 and 10 N. In each concentration of acid the potential of the titanium electrode was measured with regard to time. The results are shown in curves as plotted in Figure 14.

From these curves it is apparent that in each concentration of the sulfuric acid the potential of titanium becomes less noble (more anodic) in the course of time and that the higher the concentration, the more anodic the potential. The potential in acids of lower concentration, especially in 1 N, showed some fluctuations. In Figure 15 the most negative potentials obtained in sulfuric acid and in hydrochloric acid of various concentrations are plotted against the concentration in normality.

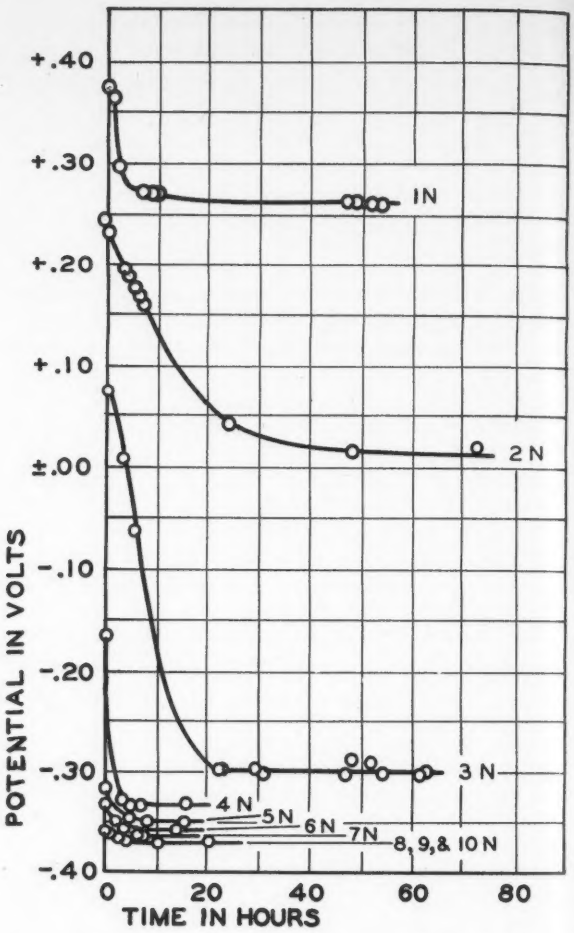


Figure 14—Electrode potential (ε') of titanium (Remington Arms) in various concentrations of sulfuric acid in the presence of air, plotted against time.

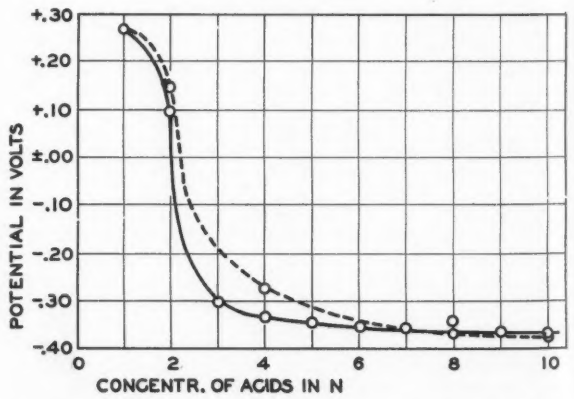


Figure 15—Electrode potential (ε') of titanium (Remington Arms) versus concentration of sulfuric and hydrochloric acid (broken curve).

The experimental procedure for measuring the titanium potentials in hydrochloric acid was exactly the same as in the case of sulfuric acid. During the measurement in 8 N hydrochloric acid, the titanium electrode was purposely taken out of the acid when

the potential was —0.335 volt. The electrode was washed first with tap water then with distilled water and finally allowed to dry in the air for half an hour. After this the titanium electrode was dipped into the acid again. The potential measured now was —0.187 volt, and gradually resumed its original less noble potential of —0.335 volt after eight hours. This shows clearly the effect of the protective film formed on the titanium surface during drying and the connection with the potential behavior (see discussion).

### The Current Produced by the Titanium Electrode

This experiment permits verification of the presence of films on metallic electrodes in a more simple way. If an appreciable polarization of the anode (which becomes more cathodic) takes place, protective films are present on the surface. The polarization can be simply observed by the decrease in the current produced by the electrode. If there is only a slight or very slight decrease in the current, either a film with wide pores is on the metal surface or there is no film.

The arrangement for the measurements is shown schematically in Figure 13B.

As soon as the switch was closed, a current was recorded on the milliamperemeter which decreased rapidly in the course of time. The current recorded by the instrument was so ephemeral that an accurate reading on it was very difficult. However, the experiments made in 1, 4, 5, 6, 7 or 9 N sulfuric acid showed a maximum current of 0.025, 0.1, 0.15, 0.24, 0.28 and 0.6 milliamps respectively. The current went down to zero rapidly, especially with acids of lower concentration, seldom lasting over five minutes. In hydrochloric acid of concentrations 1, 2 and 3 N a corresponding maximum current of 0.025, 0.05 and 0.2 milliamps was observed which also decreased rapidly to zero. If the titanium surface was scratched with a sharp, broken end of a glass rod under the acid, the current went up immediately. As soon as the scratching was stopped, the current dropped back to zero again.

Contrary to this, in hydrofluoric acid stronger than 0.2 N no decrease of current with the course of time could be observed.[10] The current increased to a maximum after approximately one hour and then decreased gradually. In 1 N acid a current of 100 milliamps could be drawn from the small cell. Polarization appreciably affected the current only when the concentration of the hydrofluoric acid was below 0.2 N. At the same time a dark film could be observed on the metal surface. This indicates that a protective film, as already mentioned, must be formed on the surface of titanium while dissolving anodically in sulfuric, hydrochloric or dilute hydrofluoric acid. This film slows down the current because of increased interior resistance. Scratching partially removes the film and consequently a stronger current flows in the circuit, which produces a new film on the bared parts of the surface. Formation of such a film in more concentrated hydrofluoric acid is evidently impossible, because it dissolves in the acid.

### Discussion

The behavior of titanium in sulfuric and hydrochloric acid can be explained on the basis of the theory of local elements, if the presence of films on the surface of the metal is considered, which play a very important role in the process of corrosion of titanium. However, it was difficult to prove that the dissolution of titanium in sulfuric and hydrochloric acids is based on the activity of local elements, although this could easily be done in the case of dissolution of titanium in hydrofluoric acid.[10] The reason is the presence of films adhering firmly to the surface of the metal.

The Figure 15 shows that the potential of titanium in sulfuric and hydrochloric acids is comparatively noble while the potential in hydrofluoric acid is around —0.77 volt if the acid is stronger than 0.5 N:

| N | $H_2SO_4$ | HCl |
|---|---|---|
| 1 | +0.263 | +0.257 volt |
| 2 | +0.097 | +0.150 |
| 3 | —0.300 | — |
| 4 | —0.332 | —0.272 |
| 6 | —0.353 | —0.342 |
| 8 | —0.368 | —0.348 |
| 10 | —0.364 | —0.372 |

These do not represent equilibrium potentials ($\varepsilon$), but dissolution potentials (therefore the designation $\varepsilon'$) and are responsible for the magnitude of the EMF developed by the local elements. The figures show clearly that especially in diluted acids (below 1 N) the potential of titanium is so noble that the potential difference of the local elements $\varepsilon' - \eta$ is negligible ($\eta$ is the hydrogen overvoltage of the local cathodes, formed by the impurities in the titanium). The minute current i produced by each of these cells is further diminished by the protective film on the metal which, of course, has some pores in which the corrosion of the metal occurs. The resistance r of the acid in these pores might be high so that the current produced by a single local element is very low:

$$i = \frac{\varepsilon' - \eta}{r} \qquad (6$$

If the film is very tight (no pores) then practically $a = \infty$ and i is zero. In such circumstances, therefore, the metal will not corrode at all. This is nearly realized in the case when titanium is immersed in sulfuric or hydrochloric acid of a concentration below 2 N or in hydrobromic or hydroiodic acids of any concentration.

It was assumed that only the impurities present in the titanium having a good electrical conductivity act as local cathodes. The protective layer on the metal, covering the cathodes, may act as a cathode only in case it has a low electrical resistance and a low hydrogen overpotential. However, it could be concluded from the behavior of the titanium in different acids, that the protective film might not have the aforementioned properties, and that its contribution as a cathode to the rate of dissolution is negligible as compared with the rate developed by the metallic cathodes. This will become more evident during the further discussion.

As shown in Figure 14, the potential of titanium becomes more negative in the course of time, especially in acids of lower concentration. The increase in the negative value of the potential is very effective during the first 10-30 hours, then the increase is much slower. Correspondingly the rate of dissolution

in sulfuric acid at first increases rapidly (in the course of the first 10-50 hours, see Figures 2, 5, 8, 9, 10) then slowly (Figure 10). In some cases passivation occurs after the maximum rate was reached (Figures 2, 5, 8, 9). In some cases it took an appreciable time to overcome the original passivity of the sample (Figures 3 and 4). Evidently, the increase in the negative potential in the course of time is connected with the widening of the pores. The rate of widening in turn depends on the nature and strength of the film on the titanium and on the nature of the acid. If the pores become widened, new local cathodes become uncovered[14] and go into action. The total current per $cm^2$, therefore, will be:

$$I = z' \frac{\varepsilon' - \eta}{r} \qquad (7$$

where $z'$ is the number of active unshielded local cathodes per $cm^2$ of the dissolving titanium surface. The total number is z, the number of cathodes shielded by the protective film is, therefore $z - z'$. Since the basic reaction of dissolution of titanium in acids is

$$Ti \rightarrow Ti^{2+} + 3e, \qquad (2$$

the velocity of corrosion

$$V = \frac{\Delta x}{\Delta t \cdot F} \qquad (5$$

which corresponds to the current I (eq. 7), can be expressed in terms of weight units ($mg/cm^2hr$, $mg/cm^2min$) or hydrogen volume units ($mm^3/cm^2hr$). For this purpose only a factor k must be added to eq. 7[15]; (F is the area of the corroding surface):

$$\frac{\Delta x}{\Delta t \cdot F} = V = k \cdot z' \cdot \frac{\varepsilon' - \eta}{r} \qquad (8$$

The corrosion process in sulfuric acid starts at points where the protective film is weaker and can be penetrated by the ions of the acid. Evidently at these points the film breaks down and a larger number of local cathodes become exposed to the acid, so that the velocity increases for two reasons: increasing $\varepsilon' - \eta$ (eq. 8 and Figure 14) and increasing $z'$ (eq. 8 and Figure 10). Then, later the velocity may increase only because of increasing $z'$ (Figure 10). The pitting-like attack of the acid can be seen on all micrographs of the corroded titanium surface (Figure 7). The curves of Figure 10 cannot be explained if it is assumed that only the protective film on the surface of titanium acts as a local cathode. Because of the breakdown of this film during the period of increasing rate of corrosion, its surface area must decrease; but this is connected with an increase of current density and hence, with an increase of the hydrogen overvoltage of the film. Thus, it soon will come to an equilibrium and a further increase of the anodic area will not be connected with an increase in the rate of corrosion. Since the data plotted on Figure 10 do not show this, it must be assumed that the rate developed by the surface film as a cathode is negligible compared to the rate produced by the activity of single local cathodes, gradually uncovered by the breakdown of the protective film as the corrosion proceeds.

The curve Figure 6 is well explained by the simultaneous action of three factors with increasing concentration of the acid:

1) Increasing in the number of acting local elements $z'$,
2) In their EMF and
3) Decreasing of the resistance r of the acid (eq. 8).

The fast increase in the rate of corrosion of the less pure sintered Bureau of Mines sample (Figures 11 and 12) is caused mainly by the increase of $z'$ in the course of time.

The pure Bureau of Mines titanium has a very interesting property of selfpassivation as shown by Figures 2, 3, 4 and 5. The acid first destroys the film which was formed on contact with air, then it attacks the metal for a period and finally the titanium becomes passive again because of the formation of a new kind of protective film. Since this selfpassivation was observed only on the pure Bureau of Mines titanium, it must be assumed that this metal contains an impurity which helps to create a new acid-resistant coating after the old oxide layer has broken down. The formation of the new coating can be explained as follows: Although the rate of corrosion of titanium was low, nevertheless the presence of trivalent titanium salts (eq. 1 and 2) could be recognized in the acid by their color after an interval of dissolution (the acid concentration becomes weaker and that of the titanium salts becomes greater). Since oxygen was present, the oxydation into the tetravalent state occurred (eq. 3 and 4) and simultaneously the hydrolysis of the oxydation product. Now it is very probable that precipitation of the products of hydrolysis started on the specific impurities (local cathodes) of the Bureau of Mines titanium as precipitation centers, covering them and the metal gradually by a protective layer. This passivation cannot be explained if it is assumed that the layer acts as a cathode of the local elements.

The breakdown of the layer formed in sulfuric acid occurred in turn when the samples were aerated (Figures 8 and 9). Oxygen caused a higher rate of corrosion and the breakdown of the layer, which action might be supported by the mechanical action of agitation. A slightly higher rate of corrosion was observed as compared with the rates obtained in stagnant, rich-in-hydrogen acids. The period of dissolution lasted a shorter time, indicating that the process of hydrolysis and precipitation was faster and the protective film formed subsequently was more stable than the original one. Since the rate of corrosion of titanium was slow, it is believed that the rate of diffusion of the soluble corrosion products was not appreciably influenced by the agitation of the acid.

The composition of the films was not investigated, but it is supposed that they consist of titanium oxides, hydroxides or basic salts of titanium. Their tightness and low solubility increase in the order $HF \rightarrow HCl \rightarrow HBr \rightarrow HI$, so that a protective film on titanium is formed much faster in hydroiodic than in hydrochloric acid. The noble potential of titanium (Figure 15) in sulfuric and in the last three acids also is demonstrated by the fact that under these conditions titanium does not displace noble metals from

their salt solutions. Even platinum tetrachloride added to the solutions of the four mentioned acids was not precipitated by titanium. But this precipitation can start in some seconds, if the protective film is removed by addition of fluorides or hydrofluoric acid, which quickly dissolve the protective film on titanium.

Scratching does not help because the film is immediately regenerated on the places where it was removed mechanically.

When even small amounts of ammonium fluoride were added to one of the four mentioned acids covering the pure titanium rapid acceleration of the reaction of dissolution occurred. Simultaneously, because the protective film was thereby removed the displacement of noble metals from their salt solution by titanium occurred. The rate of dissolution of titanium therefore increased greatly, because the particles of the noble metal formed numerous new local cathodes on its surface.

A further reason why the potential of titanium is much more anodic in hydrofluoric than in the four acids mentioned is that the concentration of titanium ions $[Ti^{3+}]$ in this solution is very low because of complex ion formation with hydrofluoric acid:

$$Ti^{3+} + 6F^- \rightleftharpoons [TiF_6]^{3-}$$

The low concentration of $[Ti^{3+}]$ produces a very negative potential of titanium. Because of the stability of the complex, it is very probable that only the $[TiF_6]^{3-}$ are in the solution, which in the presence of air oxidizes to $[TiF_6]^{2-}$.

Thus in the way shown the electrochemical behavior of titanium and its dissolution in acids, its corrosion resistance and its quick destruction by hydrofluoric acid or by soluble fluorides (in the presence of other acids) can be well understood.

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## ERRATUM

**Recommended Practices for Surface Preparation of Steel.** TP-6G Surface Preparation for Organic Coatings. *Corrosion*, **6**, No. 8 276-282 (1950) August. Page 281, Col. 1, Line 20. Change to read

2) The increase in durable life of the organic finish. Changing "decrease" to "increase."

(Note: Reprinted copies of this article also require correction.)

# Stress Corrosion: Its Relation to Other Types of Corrosion*

By U. R. EVANS*


## Abstract

Corrosion damage can be classified into: 1) General (unlocalized) corrosion, 2) Pitting, 3) General intergranular corrosion, 4) Stress corrosion, 5) Corrosion fatigue. Of these, the first causes least weakening, while the last two cause the most weakening. Stress corrosion, differs from corrosion fatigue in requiring pre-existing paths of weakness (generally but not always intergranular); thus it occurs only on some materials after certain heat-treatments. Corrosion fatigue which manufactures its own disarrayed material as the crack proceeds can be obtained on almost any material exposed to alternating stresses in a corrosive environment. Preventative measures are briefly surveyed.


## Introduction

THE OUTSTANDING FEATURE of stress corrosion is the fact that, while the passage of metal into the combined state is often trivial, the damage is immense. It may be instructive to consider its relation with other types of corrosion in which a greater amount of chemical change produces far less damage. The various types will be considered in turn.

## General (Unlocalized) Corrosion

During the corrosion of iron in acid or of aluminum in alkali, the whole surface often becomes attacked; the shielding of certain portions by oxide films is impossible, since oxide cannot exist in equilibrium with such liquids.

General corrosion can, however, arise in another way. A horizontal plate of zinc fully immersed in a neutral chloride solution for a long period and then examined will be seen to have suffered attack over the whole surface. In this case, however, it would be untrue to say that every point is being corroded simultaneously. At any instant during the period of immersion, there are certain (anodic) areas which are corroding and other (cathodic) areas which are, for the moment, immune; but the boundaries of the anodic areas are at some places slowly advancing—possibly through undermining of the adjacent (film-covered) cathodic areas—and at other places they are slowly receding—possibly through the passivating action of the alkali formed nearby by the cathodic reaction. Through this slow movement of the boundaries, every point becomes anodic sooner or later—even though the ratio of anodic to cathodic areas does not greatly change. Thus in the end there remains no part of the surface which has escaped attack.

The slow but continuous alteration in the "electrochemical map" showing the division of the surface into anodic and cathodic regions has been brought out clearly in the work of Noordhof,[1] who used a dielectrode consisting of two silver/silver-chloride electrodes arranged in concentric tubes, one projecting beyond the other (Figure 1). The symmetrical combination

$$Ag/AgCl/KCl \ldots KCl/AgCl/Ag$$

can produce no current *per se*, but if the dielectrode tip is placed in a position where there is a potential gradient due to a neighboring corroding surface, and if the two halves of the dielectrode are joined through a sensitive current-measuring device, a deflection will be registered; the direction of the current allows the anodic and cathodic areas to be distinguished; in this way the advance or recession of the boundaries can be followed. Indeed it is possible to calibrate the dielectrode in a vessel containing liquid through which known micro-currents are made to flow, provided from an external source of EMP and measured with an external microammeter; after calibration, it can be used to estimate the corrosion currents passing between the anodic and cathodic areas of the zinc specimen. Noordhof found them to be roughly strong enough to account for the corrosion-rate measured chemically. This equivalence between corrosion-current and corrosion-rate, in the sense of Faraday's Law, had already been established for several (easier) cases where the currents were stronger and the geometrical positions of anodic and cathodic areas more stable. Such cases include iron partially immersed in chloride solution, studied by Hoar;[2] iron corroding at a scratch line in sodium bicarbonate solution of con-

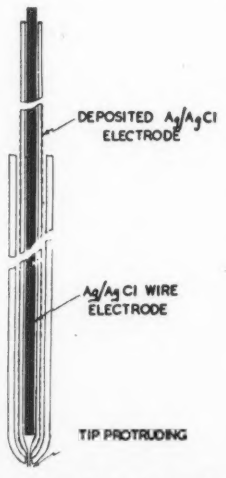


Figure 1. Noordhof's dielectrode.

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centration lying between the corrosive and passivating ranges, studied by Thornhill;[3] and zinc partially immersed in chloride solution, studied by Agar.[4] The methods used at Cambridge by these four experimenters were based on definitely different principles, and the researches provide independent quantitative evidence for the electrochemical mechanism of corrosion.

## Pitting

In certain cases an anodic corrosion reaction is autocatalytic so that attack, having once started at a sensitive spot on a surface, continues at that point in preference to others, producing pitting. The causes of the autocatalytic character have been considered by Hoar[5] and by Edeleanu.[6] In general, two types of anodic change are possible;[7] metallic cations can pass into a liquid giving in effect a solution of a salt[5] or the metal can combine with $OH^-$ ions to produce a film of oxide or hydroxide, which tends to stifle further attack; the former change will usually predominate at low pH and the latter at high pH, but over an intermediate range of pH both changes can proceed together. Now when $OH^-$ ions are discharged to produce a film, the solution becomes more acidic, making the conditions increasingly favorable for the alternative reaction (the formation of a soluble salt). If the current density is low, and the discharge of $OH^-$ ions slow, the excess of $H^+$ ions will largely be dissipated by diffusion; if the current density is high, hydrogen ions will accumulate to a higher concentration, before loss by diffusion balances production by anodic action. Imagine a piece of metal placed in a solution of pH value high enough to make the discharge of $OH^-$ the main reaction. If, for any reason, anodic current density is momentarily high at one particular point, it produces conditions increasingly favorable to the formation of soluble product. Thus attack at this point becomes permanently faster than at the places around where the film continues to thicken and protect the metal.

The matter can be considered quantitatively if the solubility product of the hydroxide or oxide is known and if it is assumed that the corrosion proceeds sufficiently slowly to maintain equilibrium relations between hydroxyl ions, metal cations and the hydroxide. That assumption may not always be fulfilled but Edeleanu has shown that if the basis of argument is accepted aluminum should suffer pitting in the neutral weakly acid range while iron should suffer pitting or localized attack in the weakly alkaline range. These expectations are fulfilled. It is found that a specimen of aluminum, even when subjected to anodic attack with a current applied from an external EMF through a separate electrode as cathode, still suffers pitting in the range of pH indicated; in such an experiment there is no cathodic region on the specimen under study, so that the relative immunity of the regions between the pits cannot be attributed to cathodic protection.

In the case of iron, the localized attack when an alkaline substance is added to a chloride solution has been demonstrated on several occasions,[8] the dangerous character of most alkaline inhibitors, which intensify attack when added to a saline water in amounts sufficient to stop attack on the main part of the surface but not at certain susceptible spots, cannot be too often stressed. The danger is not sufficiently pointed out by those who advocate inhibitive water treatment as the cure for all corrosion troubles. Such treatment may be effective when used with judgment but can make matters worse than before when used blindly. It must be admitted that a universal inhibitive treatment which is both safe, efficient and suitable for general use has yet to be found; but the results of Palmer[9] are encouraging.

It is natural to ask what are the points where attack first starts and, having once started, becomes self-stimulating. In early work on aluminum, Seligman and Williams[10] attributed pitting to the presence of holes which had been "closed over" by mechanical working. Indeed they produced pitting artificially by making such holes and nearly closing them with a hammer. In general, aluminum corrosion starts at surface blemishes. In a truly remarkable research, Brown and Mears[11] cut a specimen of aluminum in two; on one half they covered up with wax all the small points where attack was starting, while on the other they covered up the whole surface except those points of attack, which were intentionally left bare. On joining the two pieces through a microammeter and dipping them in a suitable liquid, a current was found to pass between the blemishes at anodes and the blemish-free regions as cathodes, which was sufficiently strong to account for the corrosion-rate in the sense of Faraday's Law. This proved the electrochemical character of the localized corrosion of aluminum. Other experiments in which "blemishes" were intentionally produced by engraving scratches upon the surface gave similar results.

The main conclusions drawn from this work can readily be accepted, but one slight modification may be called for. Whitwham[12] has found that an anode made of aluminum alloy containing 4 percent of copper corrodes about 19 percent faster than Faraday's Law would predict—evidently owing to hydrogen evolved from the anode itself. Schikorr, quoted Ergang and Massing,[13] had made a similar observation on unalloyed aluminum in 1933, the excess being apparently 14 percent. Edeleanu[14] measured the hydrogen from pure aluminum anodes and found it to represent 20 percent of the electricity passing through the circuit. Thus it would seem that the corrosion-rate may prove in some cases to be rather higher than the equivalent of the current passing from the anodic points to the main cathodes outside. Of course, the hydrogen may itself be regarded as coming from cathodic islands (perhaps of atomic size), situated within the anodic areas (themselves very small); but there is no concrete evidence that this is the case.

On steel, Homer[15] studied the starting points of the localized corrosion produced by a carbonate-chloride solution of suitable concentration. On smooth surfaces corrosion usually started at certain inclusions, notably sulfide particles or rolled-in scale. Only a proportion of the sulfide inclusions acted as starting-points, while silicate and aluminum inclusions appeared never to act in that way. A fresh scratch made on the metal could also act as starting

point and when the whole surface was roughened by abrasion, the influence of inclusions became unimportant.

It is obvious that pitting produces locally a more rapid penetration into the metal than the same amount of corrosion uniformly spread out, and in some cases may affect the strength. A line of pits falling on a minor groove due to previous scratching or on a string of inclusions, will presumably cause marked stress-intensification if the corroded metal is subjected to stress in a direction at right angles to the line; similarly in a case where inhibitor has been added to the liquid in quantity sufficient to prevent corrosion of the immersed portion of a partly immersed plate but insufficient to protect the water-line zone, the trench cut into the metal along the water-line might prove very damaging to strength under certain circumstances.

### General Intergranular Corrosion

If the intergranular zones within a metal are more easily attacked by a given liquid than the grain-interiors, intergranular trenches will appear. If, however, the attack is distributed over all, or nearly all, those grain-boundaries which meet the surface, neither the rate of penetration into the metal nor the loss of strength need be very serious—although clearly both of these will vastly exceed the figures obtained for the same destruction of metal uniformly spread out. In general, intergranular corrosion is only pronounced if the liquid possesses a selectively corrosive character, capable of attacking the material of the grain-boundaries, but leaving the grain interiors untouched, or only slightly attacked. Much stress has been laid on the electrochemical character of intergranular attack and on the necessity for the grain-interiors to be cathodic towards the grain-boundaries. However, such a relation may not be essential. To take an extreme case—a hypothetical material produced by cementing together grains consisting of an organic plastic with metallic potassium would undergo marked intergranular attack when introduced into water, although no electrical currents would flow from the plastic. Undoubtedly, when the corrosion is subject to cathodic control (e.g. limited by the rate of supply of oxygen to the cathode), the presence of platinum-like grains and zinc-like intergranular substance will favor rapid disintegration of the grains. In such case, the damage may accurately be ascribed to electric currents flowing from a large cathode to a small anode—a combination which always favors intense attack owing to the limited area upon which the anodic destruction is concentrated. But, if the immunity of the grain-interiors was due to their cathodic polarity, then, when the whole material was made anodic with a current supplied through a separate electrode as cathode from an external source, intergranular corrosion should give place to nearly uniform corrosion involving the whole surface. At least in the particular form of intergranular corrosion known as stress corrosion (discussed below), this is not the case; Whitwham's experiments[16] show clearly that the application of an anodic current greatly accelerates the stress corrosion cracking of susceptible aluminum alloys, the external surface remaining unattacked. The concentration of the attack on the grain boundaries and the immunity of the grains themselves is better ascribed to Edeleanu's autocatalytic mechanism discussed above.

Undoubtedly, on many light alloys undergoing intergranular corrosion currents do flow from the grain boundaries as anodes to the grain-interiors as cathodes. This was indeed shown by the work of Dix and his colleagues[17] in the course of which the potential of a specimen having the grain-boundary zones masked with varnish was compared with that of another specimen on which the grain-interiors were masked with varnish; a definite difference was found. It was, however, frankly recognized that the width of the zone taken to represent the grain-boundaries was greater than was desirable.

Some of the most interesting cases of intergranular attack concern nearly pure metal. Lacombe and Yannaquis,[18] subjecting an electropolished surface of aluminum of 99.99 percent purity to hydrochloric acid, found that there was rapid attack along some of the grain-boundaries—but not along all. On the whole, the grain-boundaries attacked were those separating grains of distinctly different orientation—although the angle between the boundary and the crystal-direction itself influenced the result. In general, those grain boundaries at which the atoms should be in the greatest disarray were the ones most rapidly corroded. Twin-boundaries which need involve no disarray escaped attack.

At first sight, these results would seem to point to a simple crystallographic explanation of intergranular attack. Atoms at grain-boundaries, especially boundaries where there is marked contrast between the orientation of the two grains, should be more easily removed than those situated elsewhere, the activation energy of the removal process being lower.* But, if this is all, why is not marked intergranular attack a more common phenomenon? Again, why, as Roald and Streicher[19] have shown is the tendency to intergranular attack different for samples of aluminum differing in purity and why are both the intensity and the character of the attack different in acids and liquids, being intergranular in acid for some samples and in alkali for others? Those who state that Lacombe and Yannaquis' results rule out the importance of impurities, on account of the high purity of the material used by them, forget that, although the *difference* between the impurity concentration at the grain-boundaries and grain-interiors must have been small in very pure material, the *ratio* may well have been high. Actually the trace of foreign atoms present in exceptionally pure matals will generally, under equilibrium conditions, tend to congregate at the grain-boundaries separating grains of contrasted orientations, because such places will provide a selection of holes, large and small, into which the badly-fitting foreign atoms can take refuge and thereby reduce the energy of the system to a minimum. Atoms of a metal *anodic* to the dominant metal will be preferentially attacked. Their disappearance cannot by itself suffice to explain the intergranular

* Alternatively, rapid attack might be produced if one grain was strongly anodic to its neighbor on account of their different orientations.

trenches produced, but the attack upon the foreign atoms at intergranular boundaries may start just that sort of autocatalytic process which will cause attack to develop at these places and may also cause it to follow intergranular paths in preference to others. Atoms of a *cathodic* foreign metal—if in solid solution at the grain-boundaries—will pass into the liquid along with the aluminum and will then be redeposited as metal, creating local cathodes which will increase the chance of attack on adjacent aluminum atoms, as opposed to distant ones; for even in concentrated (highly conducting) solutions, where the resistance has no appreciable influence on the rate of corrosion, the parts of an anodic area close to a cathodic particle will suffer attack—other things being equal—more rapidly than those far away.

It is logical to think that the nature and distribution of impurities may be more important in nominally "pure" metals than in frankly "impure" ones and may be specially important in connection with intergranular attack. These fundamental points ought to be cleared up before the more complicated cases—such as heat-treated alloys—can be properly understood.

## Stress Corrosion

When intergranular corrosion is distributed over all, or most, of the intergranular paths which meet the free surface of the metal, both the rate of penetration and the rate of loss of strength will—for a given destruction of metal—be low. When, however, it is concentrated upon a limited number of paths the penetration and weakening will be far more rapid. If an aluminum alloy which has received a heat-treatment capable of rendering the grain-boundaries sensitive to corrosion is subjected to tensile stress during its exposure to the corrosive substance, the penetration follows a *limited* number of paths which run roughly perpendicular to the stress direction. In such a case, stress and corrosion, acting together, produce failure far more quickly than corrosion acting alone and at stresses which would not produce failure at all in the complete absence of corrosion. But this disastrous combination of stress and corrosion does not always cause failure by an intergranular path. Magnesium alloys fail by transgranular stress-corrosion, although it would excite no surprise if further work should show that even here the path follows the junctions of sub-grains. In general, stress corrosion may be said to follow the path which presents least obstacle to the combined action of stress and corrosion.

It is easy to understand why corrosion and stress acting together would concentrate the attack on a limited number of paths, running in a direction at right angles to stress. Corrosion alone may start to separate two grains until it comes up against some chemically strong bridge, and then—in absence of stress—it will almost cease to make progress. If stress is applied, the stress concentration set up around the now isolated bridge will rupture it and the crack may for a time progress mechanically until it comes to a mechanically strong bridge and then it will in turn cease to make progress. Now, however, the chemical (or electrochemical) influences are able to deal with the bridge and thus by combination of the two destruction agents the crack proceeds indefinitely. The chance of a permanent hold-up depends on a mechanically strong bridge and a chemically strong bridge coinciding. If the two properties are uncorrelated, this chance may be the product of two small quantities and thus very small. If they are mildly correlated stress will assist corrosion less; if the correlation is complete, the time needed for an intergranular fissure to penetrate to a given depth will probably be much the same whether stress is absent or present.

If a specimen is broken by the combined action of corrosion and stress the life is practically the same whether stress is applied in the opening stages or not. In either case, the first effect appears to be a general intergranular attack, distributed over almost all the grain-boundaries. Only where a certain degree of sharp trenching has thus been obtained will stress (if present) start the more rapid cracking at a few favorably orientated boundaries, which will comparatively soon cause failure. Apparently applied stress becomes effective when the intergranular trenching is sufficient to cause a certain degree of stress intensification. Comparative experiments showed that two sets of specimens exposed to corrosion influences 1) with stress applied from the outset 2) with stress applied only during the later period, enjoyed nearly the same lives; Whitwham[12] found this under conditions of anodic acceleration, and Edeleanu[14] without acceleration. But while stress is not needed in the early stages, corrosion is certainly needed in the later stages. Gilbert and Hadden,[23] studying the stress corrosion of aluminum-7 percent magnesium alloys in 3 percent sodium chloride—which needs oxygen to stimulate the cathodic reaction—stopped the progress of the cracking competely by shutting off the oxygen supply. When oxygen was readmitted cracking was resumed and the specimen quickly broke. Edeleanu,[14] working on the same alloys, found that he could stop cracking at an advanced stage where the specimen was due to break within a few seconds, by applying a strong cathodic current; this doubtless served to raise the pH at the tip of the crack, stop the autocatalytic reaction and produce a film on the metal, so that the crack abruptly ceased to advance and the specimen remained unbroken for hours. Edeleanu's results suggest that the conditions determining the occurrence or non-occurrence of corrosion-cracking are essentially the same as those which determine pitting. If the conditions are such as to produce filming at the tip of the crack, the crack will not advance—even though stress is applied; if they are favorable to soluble products and the absence of film, the crack will advance even if the stress applied be low. It is difficult to reconcile his results with the idea that the function of the stress is to break a film which would otherwise hold up attack.

It is possible that stress acts in part by distorting the lattice of the metal and thus shifting the electrode potential in a direction favorable to attack—a factor which is probably important in the corrosion fatigue of steel. However, there is little or no evidence of

this in the cracking of light alloys under steady tensile stress—nor is the assumption needed to explain the results.

While it is generally agree that the stress corrosion cracking of aluminum alloys only occurs after heat treatments which produce at the grain-boundaries matter exceptionally sensitive to attack, there is difference of opinion as to the nature of the sensitive intergranular layer. Dix Mears and Brown[17] have developed the view that in aluminum-copper alloys, particles of $CuAl_2$ are deposited at the grain-boundaries leaving an intergranular network denuded in copper which is anodic both to the $CuAl_2$ particles and to the unchanged solid solution composing the main part of the grains. The denuded layer is thought to provide the path for the intergranular attack. Akimov[20] and later Tomashow,[21] probably independently of the American investigators, put forward a somewhat similar idea—developing it in mathematical form. On aluminum-magnesium alloys, Beerwald and Grober[22] considered that susceptibility to intergranular attack is only attained after treatment which produced an intergranular network of the $\beta$-phase. Perryman, Gilbert and Hadden[23] regard a continuous network of $\beta$-phase as an essential condition for susceptibility after treatment below 212° C for a week, but find susceptibility also in material treated above 212° C although here the $\beta$-phase occurs in small, separate "lakes," no continuous network being present. Whitwham[12] and Edeleanu[14] have obtained results which they consider to be inconsistent with some of the views quoted above. It may be best to defer comment until their work is printed.

Steel suffers cracking when held in tension in certain liquids, such as hot ammonium nitrate, hot concentrated caustic soda (as in the caustic cracking of boilers) and the ammoniacal condensates present at a certain stage of the detarring treatment of coal gas. In the latter case it is possible that the ammonia is playing the same role as the sodium hydroxide in caustic cracking. Weir[24] finds caustic cracking, at least under the conditions studied by him, to be stimulated by anodic treatment and prevented by cathodic treatment. This brings it into line with the cracking of aluminum alloys, which also appears to be an anodic phenomenon. Weir's results do not absolutely rule out the possibility that hydrogen-embrittlement may be a factor in caustic cracking—as insisted on by Zappfe.[25] Edeleanu[14] has shown that on aluminum alloys hydrogen comes from the cracks, that is from the anodic area, being formed by the so-called local reaction. Possibly this might occur on steel also and there is no doubt that hydrogen can embrittle steel. The whole matter requires further investigation, but Weir's apparatus and technique hold out hope of accumulating reliable results under controlled conditions.

### Corrosion Fatigue

While corrosion cracking under steady tensile stress can produce very serious mechanical failure, it is fortunately only produced on certain materials in certain conditions. Its main technical importance is not that stress corrosion is responsible for serious failures, but that the fear of such failures limits the use of certain otherwise attractive materials known to be liable to develop stress corrosion cracking. Corrosion fatigue produced by alternating stress can, however, cause breakdown in almost any material provided that it is simultaneously subjected to corrosive conditions and alternating stress. In corrosion-free conditions a definite "fatigue limit" can be determined for any given material; provided that the stress-range is kept below that limit, there need be no fear of failure. In presence of corrosive influences the fatigue limit disappears. Even a low range of stress—if it acts long enough—will ultimately produce failure by corrosion fatigue cracking. Thus metal exposed to alternating stresses must be carefully protected against corrosive influences. If these protective measures are relaxed even for a short period and then resumed, failure may occur more quickly under certain circumstances than if the protective measures were abandoned completely—a strange result demonstrated, and explained by Simnad.[26] A *short* intermission of the protective measures will leave the specimen with a few incipient corrosion-fatigue cracks, which, by the principles of stress-intensification, may reduce the strength below the normal fatigue limit—so that the cracking extends even when corrosion ceases. If the intermission lasts longer a larger number of corrosion-fatigue cracks remain and a family of cracks produces less weakening than a few isolated cracks. Thus the results are explained.

The difference between the occurrence of corrosion fatigue and stress corrosion is easily explained. A metal or alloy can only suffer stress corrosion under steady tensile stress if it is threaded by paths of sensitive substance and such paths will occur only in certain materials after certain treatments. But under alternating stress the metal or alloy *manufactures its own sensitive material* and almost any metal or alloy can do this. During alternating stressing disarrayed matter is formed along the gliding planes. If corrosive agencies were absent, this disarrayed matter would merely raise the elastic limit (by work-hardening) and plastic deformation would cease being replaced by elastic deforation. If corrosive substances are present while the material is being subjected to alternating stress the disarrayed matter will be dissolved away as it is being formed and the fissure will extend until fracture occurs. The corrosion fatigue crack largely follows the direction along which gliding would (under dry conditions) take place and occurs at places where disarrayed matter would be produced. Occasionally it follows the grain boundaries for short distances—as shown by Whitwham[27]—but in general it is transgranular. Fortunately the disarrayed matter only appears to be sensitive to corrosion while it is being formed. If allowed to settle down it does not seem specially liable to attack. Whitwham[27] found that if steel was subjected to dry fatigue (alternating stress without corrosion) and then to corrosion fatigue the life was no shorter than if the preliminary dry fatigue period was omitted.

The statement that strained metal is more sensitive than annealed metal to chemical or electrochemical attack has been denied. Some investigations have seemed to show that the electrode potential of strained metal is almost the same as that of annealed metal, but the potentials measured were probably not equilibrium values, since the metal was corroding during the measurements. The potential measured on a corroding specimen is a compromise value, given by the ordinate of the intersection point (P) of the cathodic and anodic polarization curves (CP and AP), as shown in Figure 2. If strain shifts the open-circuit value of the (anodic) potential, say from A to A′, the measured potential given by the intersection point, should be shifted to a certain extent (say from P to P′), provided that the cathodic curve is not affected. If, however, the cathodic reaction is stimulated by the strain (the cathodic curve being shifted from CP to CP″), the intersection point may occur at almost the same potential on the strained as on the unstrained metal (P″ instead of P). This apparently is what happens. Simnad,[28] however, has traced the anodic curves of cold-worked and annealed iron and has found the former to lie consistently on the "reactive" side of the latter, even though the ordinates of the intersection points were much the same for the two materials. There is no doubt that strained iron is under conditions obtaining under natural anodic attack more reactive (in the electrochemical sense) than annealed iron. Simnad's work was carried out in acid solution where no oxide film could survive; thus the greater reactivity of the strained iron cannot be attributed to film rupture.

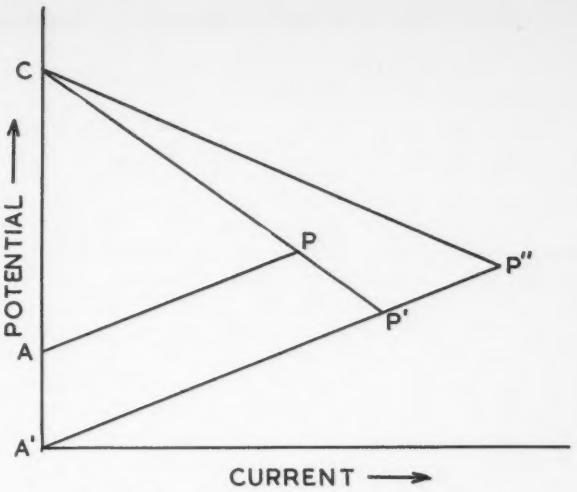


Figure 2. Curves showing principles of Simnad's work.

### Preventive Measures

Stress corrosion may be caused by 1) residual stresses left in the material as a result of cold-deformation or quenching, as well as by 2) constraint due to lack of precision in the construction of a plant and 3) stresses arising from service conditions. If all these three causes produce tension at the same point, the effects will be additive and the combination may be dangerous even though the stress due to each one (acting alone) might be harmless. Internal stresses, and sometimes stresses due to structural misfit, can be eliminated by suitable annealing but in some alloys care must be taken that the heat-treatment does not itself produce chemically sensitive paths in the material. Applied tensional stresses, or alternating stresses arising in service, must be kept within safe limits or materials must be chosen which are relatively resistant. By introducing compressional stresses into the surface layers of the material it is possible to counteract to some extent the bad effect of applied tensions or the tensional half-cycles of alternating stresses. Thus peening, which leaves the surface layers in compression and which has long been used to combat the dangers of dry fatigue is found also to increase the corrosion-fatigue life of steel under suitable conditions. This was shown by the measurements of Gould,[29] who compared a high-carbon steel in the peened state with the same steel carrying a finely ground surface. The peened surfaces enjoyed a longer fatigue life when wetted with sea water (from Chichester Harbour) or with 0.005 normal sulfuric acid. But in certain mixtures containing sodium chloride along with carbonate and bicarbonate in quantities insufficient to stop attack altogether the fine-ground specimens survived longer than the peened ones. Peening is sometimes condemned because it leaves a surface to which protective coatings will not easily adhere but Gould found that if a sufficiently thick peened layer had been produced by the use of fairly large shot or fairly high pressures, a certain degree of roughening could be applied by grit-blasting without loss of the corrosion fatigue resistance conferred by peening.

Another method of obtaining compressional stresses in the outer layer is by the nitriding of certain steel-containing elements which form hard but incompressible nitrides. Tests by Inglis and Lake[30] showed excellent figures for corrosion-fatigue behavior in such cases.

Surface treatment has been advocated for light alloys. If applied by means of abrasion, care should be taken that the abrasion direction of a member runs parallel to the direction in which stress will be applied in service. If it is perpendicular the grooves will certainly act as stress-raisers—the importance of direction being shown by the measurements of Perryman and Hadden,[23] who offer a somewhat different explanation. Edeleanu[14] utters a warning against surface treatment of aluminum-magnesium alloys *before* ageing, since it will favor the changes responsible for intergranular susceptibility. Surface treatment *after* ageing is less dangerous. Even very slight, unintentional surface treatment may, in Edeleanu's opinion, suffice to set up corrosion cracking, which, once started may penetrate through a large cross-section. This *caveat* applies in particular to solution-treated material and may not be necessary for commercial material which has received the heat treatment customary in industry today.

Many of the methods used to prevent stressless corrosion deserve consideration in connection with corrosion fatigue or stress corrosion but in practice

they are not all effective, while some are dangerous. A coating of copper—liable to set up pitting even under stressless conditions if the coating contains discontinuities—is still more dangerous under stress, which may produce new discontinuities or open out latent discontinuities already present. Thus copper coats on steel are said to have shortened the corrosion fatigue life instead of lengthening it. Zinc—which is anodic to steel—can protect steel against corrosion fatigue even when the zinc coating is definitely discontinuous, but none of the numerous methods of application are ideal. Hot galvanizing, by introducing a brittle alloy layer, may actually favor the inception of fatigue cracks and thus shorten the dry fatigue life. If used for corrosion fatigue conditions, the process must be so conducted as to minimize the formation of the alloy layer, or produce it in suitable textural form—a problem to which the extensive results of Bablik[31] might be suitably applied. Electrodeposition is doubtless better but care must be taken not to leave a hydrogen charge which would cause embrittlement of another type. Sprayed zinc coats applied with the wire pistol have given encouraging results in laboratory corrosion fatigue tests at Cambridge but consideration must be given to the type of surface roughening used to insure the desired keying of the deposit. Paints richly pigmented with metallic zinc—based either on an organic vehicle (chloro-rubber or polystyrene[32]) or on an inorganic (cementiferous) vehicle[33]—have given favorable results in Huddle's tests.[34] But some caution should be exercised in drawing conclusions about service behavior over long periods from laboratory tests which, for obvious reasons, use high frequency, high stresses and short periods of testing.

Zinc-rich paints are being tested for the prevention of stress corrosion cracking in susceptible light alloys. Zinc is anodic to these materials when they carry oxide films but cathodic to the same materials when they are free from films. This may explain why zinc-rich paints (or zinc contact-strips) sometimes prevent the inception of corrosion cracking but fail to stop it when it has once fairly started.

Soluble inhibitors, such as the chromates, or the emulsifying oils, are sometimes added to cooling water to prevent corrosion fatigue.

## Summary

Corrosion may be classified into

1) **General (Unlocalized) Attack,** where either the corrosion affects the whole surface simultaneously, or the regions suffering attack wander over the surface, so that every point suffers corrosion sooner or later
2) **Pitting,** where the anodic attack is autocatalytic
3) **General Intergranular Attack,** where there is specially sensitive material between the grains,
4) **Stress Corrosion,** where attack is concentrated along a limited number of sensitive paths running roughly at right angles to the stress direction, and
5) **Corrosion Fatigue,** where alternating stresses produce disarrayed material which is corroded as it is formed.

Stress corrosion cracks probably proceed readily because the chemical attack will demolish mechanically strong bridges and mechanical stress will break chemically resistant bridges, thus avoiding the holdups which would otherwise occur.

Preventive measures include the removal of dangerous (tensional) internal stresses by annealing, and the production of favorable (compressional) stresses by peening or surface treatment (alternately by chemical processes such as nitriding. In both cases, great care is needed to avoid the accidental production of a "susceptible condition" in the material.

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# A Proposed Standard Method for Measuring The Electrical Resistance of Pipe Line Coatings*

By WALTER F. ROGERS,[1] B. H. DAVIS,[2] LYLE SHEPPARD,[3] L. G. SHARPE,[4] E. R. ALLEN,[5] DONALD BOND,[6] and P. T. MILLER[7]

**I. Object:**

To determine the electrical resistance of coatings in place on existing pipe lines.

**II. Apparatus:**

The apparatus used by the Committee* consisted of the following items. Substitution may be made as required, but in no case should the substituted item be less accurate or give less satisfactory performance than the item replaced. Additional equipment may be found advisable to serve specific functions not essential to the tests.

A. *Power Equipment*

1. One portable 200 ampere, 28 volt, aeroplane type, gasoline driven engine and generator. Light weight, war surplus material.
2. One 24 volt storage battery.
3. Six 5/8-inch x 6-foot probe bars for ground bed.
4. One multirange 0-1, 0-10 ampere Weston ammeter.
5. One 10 ampere, 2 ohm variable resistor.
6. Connecting wire.

B. *Measuring Equipment*

1. One Leeds and Northrup pipe line potentiometer.
2. One copper sulfate electrode.
3. One 100-foot multiple wire cable for measuring line drop and for current input purposes during pipe calibration.
4. One probe bar.
5. Leads for connecting copper sulfate electrode and potentiometer.
6. Reversing selective switches for potentiometer.

**III. Description of Method:**

The method is based on the fact that the resistance of a conductor can be determined if the potential impressed across it and the resulting current are known. Both of these latter quantities can be measured along a pipe line. Knowing them and the lineal feet of pipe involved, the resistance is calculated. The relation may be expressed:

$$C = \frac{.262DVL}{I}$$

where:

C = Coating resistance in ohms per square foot of coating.
V = Voltage drop across the coating, volts.
I = Current picked up by pipe of length L-amperes.
L = Feet of pipe.
D = Outside diameter of coating in inches. (Commonly taken as the outside diameter of the pipe.)

The accepted unit of measurement is C, as defined above. The value of C shall always be reported. The additional use of K, the resistance in ohms per lineal foot of pipe, is optional and may be calculated by the relation:

$$K = 3.82 \frac{C}{D}$$

By virtue of the relations involved the technique is known as the Current-Voltage Method.

The application of such a test requires that current be made to flow from a ground bed to the line and return to the power source through a resistor used to control the magnitude of the current, and an ammeter to indicate the value. At different points along the test section the change in pipe-soil potential is measured, as well as the current flow in the line resulting from the imposed potential. The measured change in current flow and potential, plus the length and diameter of the pipe involved, are used to calculate the coating resistance.

Figure 1 illustrates the preferred arrangement for dividing the section of line to be examined into three lengths, together with the position of the power source and ground bed with respect to the test section.

The current output of the power source must be steady to prevent fluctuations in the value of P/S and line drop, L/D. Two power sources are available which will do this. These are rectifiers, or a combination of an engine driven generator charging a battery while current is being taken from the systetm. The wiring diagram of the generator:battery power source used by the committee is shown in Figure 2.

It is desired that each test be made at three values of current output. The maximum current output for the portable generator:battery set used by the com-

★ Submitted for publication May 10, 1951. The method given herein is among those being studied by NACE Technical Practices Committee 17—Standardization of Procedures for Measuring Pipe Coating Conductance.

1. Gulf Refining Co., Houston Pipe Line Division; 2. Gulf Refining Co., Houston Pipe Line Division; 3. Shell Pipe Line Company; 4. Humble Pipe Line Company; 5. Humble Pipe Line Company; 6. Texas Pipe Line Company; 7. Texas Pipe Line Company.

* The word "Committee" used herein refers to the authors of this article.

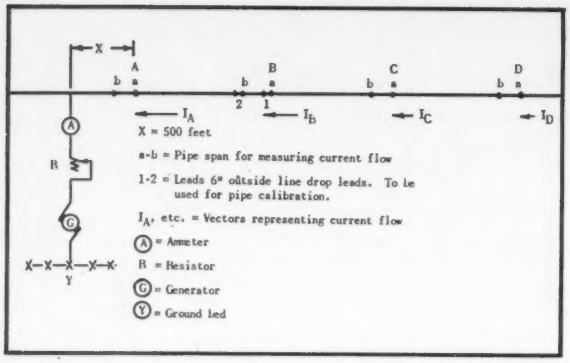


**Figure 1—Diagram of power source and division of test length into three sections with necessary contact leads.**

mittee is approximately 10 amperes, and the values of test current approximated 3, 6, and 9 to 10 amperes. If a rectifier is available with greater current output each value of current may be increased. The maximum quantity of current drained will be limited by the P/S potential which cannot exceed the range of the measuring meter. (4.0 volts for the L & N Pipe Line Potentiometer.)

The position of the ground bed should originate not closer than 50 feet from the pipe being tested. Field tests wherein the first measurement of current is made 500 feet from the drain indicate that it is immaterial whether the ground bed is placed parallel or perpendicular to the pipe. In general, a ground bed can be installed using ½-inch to ⅝-inch bars 6 feet long, placed in the ground to approximately their full length at distances of 25 to 50 feet from each other. The addition of ¼ to ½ pound of household salt and water around each rod while it is being placed in position aids in obtaining a low ground bed resistance. Using such a ground bed, current values of 10 amperes at the 24 volts of the battery : generator set are usually obtained without difficulty.

The amount of current delivered should be measured with a sensitive ammeter. If 10 amperes or less are used, a 0-10 ampere meter with 0.10 ampere divisions with estimation to 0.05 ampere should be used.

It must be recognized that the potential drop between the electrode and the pipe is a combination of potential through the coating and through the soil annular ring between the electrode and the pipe. Usually the soil IR drop is not of sufficient value to warrant deducting it from the total voltage change. Where correction is to be made for the soil IR drop, a knowledge of the soil resistance at the time of the test is necessary. The coating resistance is then calculated by the relation:

$$K = \left( V - \frac{I \rho}{2 \pi L} \ln \frac{r_2}{r_1} \right) \frac{I}{N}$$

where:

K = Resistance of coating in ohms/lineal feet.
V = Average change in P/S potential over test section.
I = Current pickup, amperes.
$\rho$ = Soil resistivity, ohms-cm.
L = Lineal feet of pipe in test section.
$r_2$ = Radius from center of pipe to electrode, feet.
$r_1$ = Radius of pipe, feet.
ln = Natural log.
$\pi$ = 3.1416.

The pipe sections must be made sufficiently long for each to pick up a quantity of current accurately detectable by the measuring meter. It appears that AB and BC of Figure 1 should be at least 5000 feet each, and CD 10,000 feet in length. The actual lengths should be positioned near road crossings or other accessible places to reduce the work of reaching the location. In some cases it may be advisable, particularly if a short length of coating is involved, to have only one section as AB. This is permissible but not encouraged because it leads to a single value of resistance for the coating.

In every case where a pipe drop is measured or a P/S measure is taken the measure is made with the

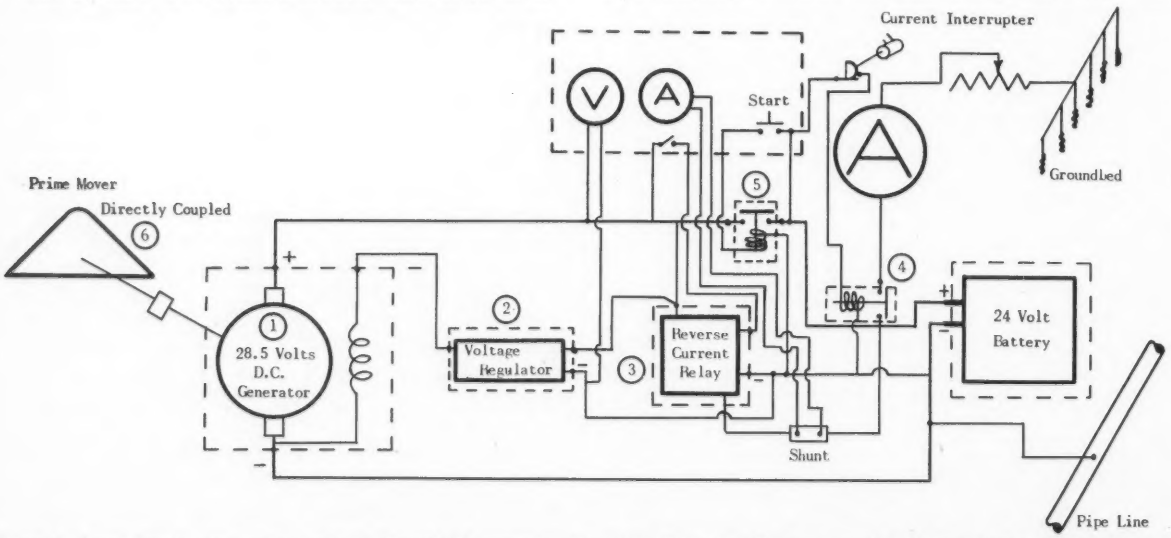


**Figure 2—Power supply, pipe coating tests. 1. Aircraft DC generator: Type P-2, 28.5 volts, 200 amp., speed 5000 rpm, Bendix Aviation Corp. 2. Regulator-Generator: 28.5 volts, Leece-Neville. 3. Generator Current Control: Current rating 200 amp., voltage rating 24 volts, Westinghouse. 4. Solenoid: 25 amp. capacity, 24 volts (For interruption of test current). 5. Solenoid (Starter): 100 amp. capacity, 24 volts. 6. Andover Motor Corp. V-32 engine by Detroit Lubricator Co., Series D-444.**

current both off and on to obtain the difference at that particular time caused by the current flow. In addition, readings are repeated three times, as described hereunder in Field Procedure for Making Tests.

It is possible to calculate the current pickup required by a test section of pipe to develop a significant difference in meter readings between the two ends of the test section. Collection of this amount of current must be exceeded for the test results to be of value. Knowing the required current, either the voltage across the coating or the length of test section can be so regulated as to allow this minimum quantity of current pickup.

Calculations have been made and are given in the Appendix to show the current pickup required where a Leeds & Northrup pipe line potentiometer with a 20 ohm galvanometer is used. The pipe resistivity must be determined by calibration for each test. If it is known that the pipe in the entire test length is laid of uniform quality steel, calibration need be made at only one point. The calibration requires that additional insulated leads be brazed to the pipe six inches outside of both of the potential leads used to measure current flow on the pipe. Details are given under Field Procedure.

## IV. Field Procedure:

As previously discussed, the Current-Voltage Method requires the test section to be sufficiently long to pick up a significant quantity of current. The greater the resistance of the coating the longer the test section must be. As stated earlier, the test portion of the pipe should be divided into at least three sections. These should be two 5000-foot and one 10,000-foot lengths, unless it is known that the coating is of sufficiently high resistance to require a longer length. If the coating resistance is medium to low these spacings will permit a significant calculation to be made for each section. If the resistance is high it may be necessary to consider the current pickup as being obtained by two 10,000-foot lengths, or even one 20,000-foot length. The location of the total test section should be made with regard to the accessibility of the site and the general nature of the area. Having selected the site, Field Data Sheet 1 must be prepared, giving the essential descriptive information. These data become part of the final report.

The second step is to select the exact spots along the pipe where the data are to be taken, and braze or weld insulated copper leads to the pipe.

The first test lead on the pipe should be 500 feet from the drain to minimize potential errors which might otherwise result from being within the field of the ground bed. At A, B, C and D two insulated leads of No. 16 copper wire or larger should be brazed to the line at a known distance apart, and brought above ground and marked for ready access. The length of the section between leads must be adjusted according to the pipe weight and diameter. From the value of the potential drop measured along this section of the line and the pipe calibration, the current flow is determined. With the current flow in the direction shown in Figure 1, a potential drop taken

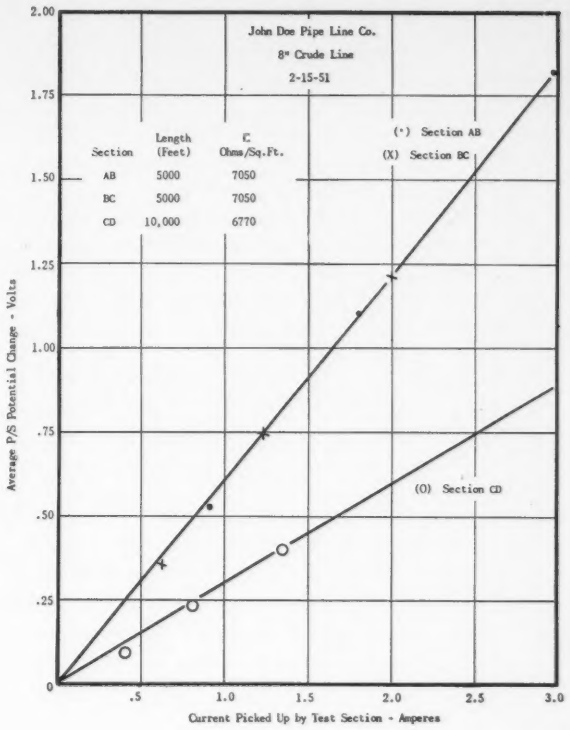


Figure 3

at the $D_{a-b}$ section would represent the current at lead $D_a$. A similar measure across the $C_{a-b}$ section represents the current at $C_a$. The difference, $I_C - I_D$, then represents the current picked up in the distance, $C_a - D_a$.

Under a normal three-section test leads are required at:

1. The drain, one lead required.
2. At 500 feet from the drain, two leads at a distance apart depending upon the pipe size. (See Figure 3.)
3. At 5500 feet from the drain, ditto 2.
4. At 10,500 feet from the drain, ditto 3.
5. At 20,500 feet from the drain, ditto 4.
6. At one location, A, B, C, or D, braze current leads 6 inches outside the two potential leads for the calibration.

At each location where leads are connected to the pipe the broken area in the coating must be repaired and the earth returned in place.

The third step in the test is to determine the pipe resistance. This is necessary because of the divergence from tabular values. The necessary apparatus is:

1. The 24 volt battery
2. Ammeter
3. Rheostat
4. Potential measuring device
5. Connecting wires

The battery, ammeter and resistor are connected to the outer, or current leads of the test point and the current regulated to a low value. The potential measuring device is connected to the inner, or potential leads. Simultaneous values of battery output and potential drop on the line are made alternately for no current flow and for three values of current. The

PIPE COATING RESISTANCE TESTS

Field Data Sheet 1
(All data refers specifically to test length)

Observers:_____ Test No._____

_____ Date_____

PIPELINE

Owner:_____ Name of Line:_____

Pipe: Size_____, Weight_____, Type & Grade_____

Joint Length:_____ Joints: Welded,_____, Screwed_____, Welded Coupling_____

Date Laid:_____ Times Reconditioned:_____ Date Last Reconditioning:_____

Remarks:_____

_____

Location of Test:_____

COATING

Materials & Structure:_____

Date Applied:_____ Yard or Field Applied:_____ Applied By:_____

How Inspected & Tested:_____

Remarks:_____

CATHODIC PROTECTION

Date Applied:_____ Present Power Source:_____ Distance From Test Area:_____

Total Amps Drained:_____ Continuity Since Date Installed:_____

P/S Potential in Test Length: Min._____, Max._____, Volts_____

Remarks:_____

_____

SOIL

Type:_____ Texture:_____ Usual Moisture:_____

Depth of Cover:_____ Soil Moisture This Date : At Top_____ At Pipe Depth_____

Remarks:_____

_____

Page 1

PIPE COATING RESISTANCE TESTS

Field Data Sheet 2

Test No._____

Date_____

TEST LENGTH & SET-UP

Sketch:

Remarks: (Power source, anode, anode location, current control, "On-Off" frequency, etc.)

PIPE CALIBRATION

| Test Point | Current, Amps.* | Line Drop, mv.* | Remarks* |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
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| | | | |
| | | | |
| | | | |

* Do not neglet to take zero reading nor to indicate polarity.

REMARKS: (Method, meters, etc.)

Page 2

PIPE COATING RESISTANCE TESTS

Field Data Sheet 3

Test No._____

Date_____

TEST DATA

| Test Point | Drain Current, Amperes "Off" | Drain Current, Amperes "On" | "Off" Readings P/S Volts | "Off" Readings Line Drop mv.* | "On" Readings P/S Volts | "On" Readings Line Drop mv.* |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | To Fill Sheet | | | |
| | | | | | | |
| | | | | | | |

* Indicate Polarity: Current flowing toward test drain point is +
Current flowing away from test drain point is -

data, together with a sketch of the entire section of line being tested, including all distance values from point to point are entered on Field Data Sheet No. 2. From the total current in the battery circuit, and the resultant potential drop on the pipe, values of amperes flow per millivolt drop are calculated. The individual values should agree within two percent of the average.

The fourth step, the actual test procedure, is the same at each point and may be described as follows:

It has been found advisable to have four men to conduct the actual test. One man stays at the generator to switch the current off and on at 1 minute or other accepted intervals, keep the current output constant, and is on hand in case trouble occurs at this point. Where available, mechanical interrupting equipment for switching the current off and on at the proper time interval may be used. This reduces the amount of work involved for the individual at the drain but does not eliminate the necessity of having him there.

The other three men constitute the measuring group. Of these three, one is the group leader and must be familiar with the test procedure, including the difficulties which may be encountered. Preferably, a second man should be equally familiar with it. The third man serves largely to string and spool wire, aid in making connections to the pipe, etc.

The wire used to connect across the pipe length over which the current flow is to be measured is strung, and holes for the copper sulfate electrode P/S potentials are made in the ground and wetted with water immediately above the pipe at three positions. These are at the lead representing the incoming current and $\pm$ 10 feet on either side. The copper sulfate and pipe drop leads are connected to the measuring meter through selective and reversing switches. Readings of the P/S potential and millivolts drop on the pipe, both with and without current flow, are measured and recorded. Both of these sets of readings are taken with the copper sulfate electrode positioned at each of the three locations noted above. A total of three off and three on readings are thus obtained for both the P/S and line drop. These data are recorded in Field Data Sheet No. 3. Average

values of the three are used. As shown on the data sheet, the direction of current flow is taken as positive (+) if flowing towards the drain, and negative (—) if flowing in the reverse direction. Similar procedure is repeated at each of the selected points, A through D, etc. After completing a set of measurements at one amperage, the current is changed and the run repeated. Data are obtained for three current values.

### V. Calculating and Reporting Data:

A typical set of calculations and final report consists of three parts and is shown attached. The report includes:

A. Field Data Sheet No. 1

B. A data sheet having:

1. A sketch of the line with the points A, B, C, the drain, etc. drawn, together with the distances involved.
2. The pipe calibration value.
3. The values of coating resistance calculated for the various sections of line tested.
4. The average values of current flow and P/S potential for each point for each test, the calculated values of change in P/S potential at each point and the average for the section, the change in current at each point, and the current pickup for the section.

C. A curve sheet on which are plotted the values of the average change in P/S potential versus the current picked up resulting from this change for each test section. Such curves should be straight lines passing through the origin. Thus, where three values of current are used four points will be available to construct the curve. If the points do not form a reasonably straight line they represent data taken under improperly controlled conditions. The calculation of the coating resistance is then made from the slope of the curve and the pipe length. The relation is

$$C = \frac{.262D\ (\text{Av. P/S Potential-Volts})\ (\text{Length, Ft.})}{(\text{Current Picked Up-Amperes})} = \frac{.262DVL}{I}$$

The conditions for a valid test are:

1. At least two values of current must be picked up by the test section which are greater than the sensitivity of the measuring meter. (For L & N pipe line potentiometer see Table I.)
2. The *change* in P/S potential measurements must be substantially free of polarization effects.
3. The curve expressing the $\Delta P/S - \Delta I$ relation must be a straight line passing through the origin and *essentially* contacting $(n-1)$ points where $n =$ the number of current values used; $(n-1)$ must not be less than 2 or more than 4.

## APPENDIX

### APPENDIX A

#### Current Pick Up Required to Exceed Sensitivity of Leeds and Northrup Pipe Line Potentiometer

The galvanometer used with the pipe line potentiometer has a 20 ohm resistance. The sensitivity is $4.6 \times 10^{-6}$ amperes per division. A difference in deflection of one division of the galvanometer is required between line drop measurements at each end of the test section. If the pipe span is taken as 100

## TYPICAL COATING RESISTANCE REPORT

PIPE COATING RESISTANCE TESTS

Field Data Sheet 1
(All data refers specifically to test length)

Observers: Smith, Jones, Ward — Test No. 10
Date 3-1-51

PIPELINE

Owner: John Doe Pipe Line Co. — Name of Line: 8" Crude Oil
Pipe: Size 8", Weight 28.55, Type & Grade API Grade B line pipe Welded
Joint Length: 30' Joints: Welded, X, Screwed, - Couplings -
Date laid: 1945 Times Reconditioned: None Date Last Reconditioning: -
Remarks:

Location of Test: MP 15.5 to 19.25, Harris County, Texas

COATING

Materials & Structure: Primer, coal tar enamel, glass fibre, asbestos felt.
Date Applied: 1945 Yard or Field Applied: Field Applied by: Machine
How Inspected and Tested: Holiday inspected and repaired when lowered into ditch.
Remarks: Total coating thickness kept at 4/32 inches.

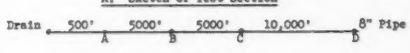
CATHODIC PROTECTION

Date Applied: 6-1-45 Present Power Source Rectifier Distance from Test Area 2 miles
Total Amps Drained: 10 Continuity Since Date Installed: Continuous
P/S Potential in Test Length: Min. .950 Max. 1.050 Volts.
Remarks:

SOIL

Type: Clay Texture: Coarse Usual Moisture Dry
Depth of Cover: 18 inches Soil Moisture this Date: At Top Moist At Pipe Depth Damp
Remarks:

A. Sketch of Test Section




B. Pipe Calibration

Point B. 1.30 amps/mv/100'

C. Coating Resistance

| Section | C (ohms/sq.ft.) |
|---|---|
| AB | 7050 |
| BC | 7050 |
| CD | 6770 |

D. Summary of Test Data

| Test Point | Off Reading P/S (volts) | Off Reading L/D (mv) | On Reading P/S (volts) | On Reading L/D (mv) | Line Current Off (amps) | Line Current On (amps) | $\Delta P/S$ (volts) | $\Delta I$ (amps) | Av. $\Delta P/S$ (volts) | $\Delta I_{A-B}$ etc. (amps) |
|---|---|---|---|---|---|---|---|---|---|---|
| Test 5-A, 3 Amps | | | | | | | | | | |
| A | .675 | 0.04 | 1.275 | 2.00 | .05 | 2.60 | .600 | 2.55 | .550 | .91 |
| B | .680 | 0.04 | 1.180 | 1.30 | .05 | 1.69 | .500 | 1.64 | .367 | .59 |
| C | .675 | 0.04 | .950 | .85 | .05 | 1.10 | .240 | 1.05 | .120 | .40 |
| D | .675 | 0.04 | .675 | .55 | .05 | 0.70 | .00 | .65 | | |
| Test 5-A, 6 Amps | | | | | | | | | | |
| A | .655 | - | 1.855 | 3.92 | 0 | 5.10 | 1.20 | 5.10 | 1.10 | 1.80 |
| B | .650 | - | 1.650 | 2.54 | 0 | 3.30 | 1.00 | 3.30 | .75 | 1.20 |
| C | .650 | - | 1.150 | 1.62 | 0 | 2.10 | .50 | 2.10 | .24 | .80 |
| D | .655 | - | .655 | 1.00 | 0 | 1.30 | .00 | 1.30 | | |
| Test 5-A, 10 Amps | | | | | | | | | | |
| A | .660 | - | 2.660 | 6.54 | 0 | 8.50 | 2.00 | 8.50 | 1.83 | 3.00 |
| B | .665 | - | 2.315 | 4.23 | 0 | 5.50 | 1.66 | 5.50 | 1.22 | 2.00 |
| C | .660 | - | 1.440 | 2.70 | 0 | 3.50 | .78 | 3.50 | .40 | 1.33 |
| D | .665 | - | .667 | 6.66 | 0 | 2.16 | .02 | 2.16 | | |

feet, the current which must be picked up by the test section and measured over the 100 foot span is:

$$I_P = \frac{(20)}{R_P} (4.6 \times 10^{-6})$$

where:

$I_P$ = Current change required for one division deflection of the galvanometer, amperes.
$R_P$ = Resistance of 100 feet of pipe, ohms.

Table I shows values of $I_P$ calculated for pipe sizes of 6 through 24 inches. As the pipe size increases above six inches its resistance decreases, and $I_P$, the current pick up required for one division, increases. In order to keep $I_P$ from increasing too much the span of pipe must be increased with pipe size. In Table I the calculated values of $I_P$ are for a 100-foot drop on 6 through 8-inch; 200-foot drop on 10 through 18-inch; and a 250-foot drop on 20 through 24-inch pipe.

Figure 4 has also been included to show the average potential drop required across coatings of K value from 1000 to 100,000 for different pipe sizes to result in minimum required values of current pick up by a 5000 foot section of pipe.

## APPENDIX B

### Special Conditions Studied by the Committee

Several problems were investigated by the Committee to determine their relative importance to the general subject of measuring the coating resistance. In this discussion only a brief resume is made and the findings given without detail. Full data are in the committee files and are available for inspection. The fact that these several conditions were studied is discussed only because the work was done and the discussion may prevent duplicate efforts from being made by others.

### 1. *Effect of Starting Potential of Line*

Tests were made to determine what, if any, effect on the calculated resistance results from the starting potential of the line. Two lines were tested which had natural potentials of .550 to .675 volts at the start, and 1.170 to 1.496 at the end of the test. The committee was unable to find evidence that the initial potential of the line was of importance in measuring the coating resistance.

### 2. *Effect of Position of Test Section to Drain*

On Tests 3-C and 3-B the drain was varied from position E to A. Thus, in one case ED was the section at the drain, and in the other case it was the farthest from the drain. When ED was next to the drain a lower resistance was found than when it was farthest away. The intermediate sections showed the same resistance regardless of the drain position. A backward-fordward test was made on Test 2-B and C to check this point. It was found that the end sections gave the same resistance value regardless of whether they were at or farthest away from the drain. There is no theoretical reason why the relation of a section to the drain should, in the absence of polarization phenomena, affect its resistance and the Committee concludes that any such effect found in the field is a matter of chance.

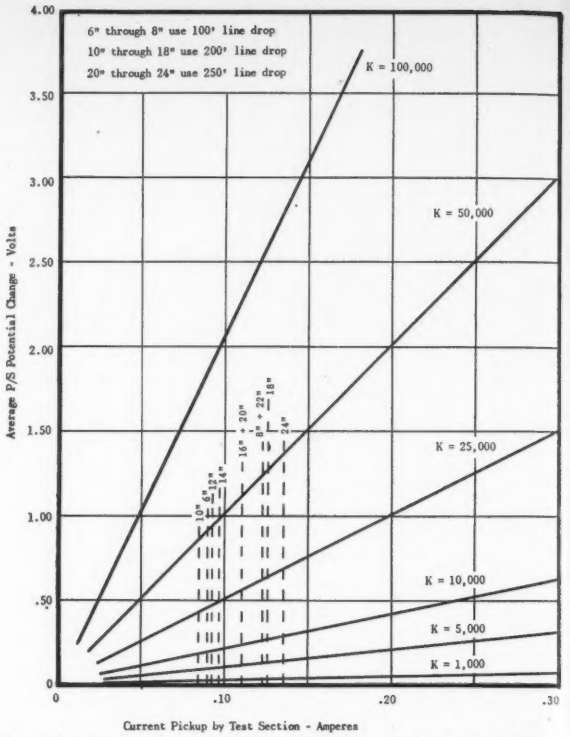



**Figure 4—Current pickup required by 5000 feet of pipe to result in one division deflection of pipe line potentiometer where line drop is taken over 100 feet to 250 feet of pipe, depending on size.**

**TABLE I**

**Minimum Current Pickup Required To Exceed Sensitivity of L & N Pipe Line Potentiometer**

| Nominal Pipe Size (Inches) | Pipe Weight (ppf.) | Pipe[b] Resistance (Ohms/100') (x10⁻⁴) | Ratio 20 Ohms / Col. 3 (x10⁻⁴) | Min. Required Current Pickup[a] (Amps/Div. of Galv. Def.) |
|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) |
| | | | | Use 100' Pipe Span |
| 6 | 18.97 | 11.37 | 1.76 | .089 |
| 8 | 28.55 | 7.56 | 2.64 | .121 |
| | | | | Use 200' Pipe Span |
| 10 | 40.48 | 5.33 | 3.75 | .086 |
| 12 | 43.77 | 4.93 | 4.05 | .093 |
| 14 | 45.68 | 4.72 | 4.23 | .0975 |
| 16 | 52.36 | 4.12 | 4.85 | .1115 |
| 18 | 59.03 | 3.66 | 5.46 | .1255 |
| | | | | Use 250' Pipe Span |
| 20 | 65.71 | 3.28 | 6.10 | 112 |
| 22 | 72.33 | 2.98 | 6.71 | .123 |
| 24 | 79.06 | 2.72 | 7.35 | .135 |

[a] Also the minimum current pickup required per test section to exceed the instrument error.

[b] Resistivity = 215.8 microhms per pound-foot. Col. 3 = $\frac{215.8}{\text{Pipe Wt. (ppf.)}}$

### 3. *Effect of Position of Copper Sulfate Electrode*

Tests were made to determine whether better P/S potential data could be obtained by placing the copper sulfate reference electrode 100 feet from the line and to one side, instead of immediately above it. The thought was that such an electrode at 100-foot spacing on the opposite side of the pipe from the anode would approach a "remote earth" position, and by averaging a greater length of line, be a better poten-

tial. The ΔP/S potential so obtained was compared with that obtained by averaging the three ΔP/S potentials made above the pipe at the lead and ± 10 feet on either side. The two measurements checked so closely that the 100-foot measurement from the line was discarded.

4. *Use of the Attenuation Method*

The data on current pick up and P/S potential change with distance from the drain were used to calculate the coating resistance by the attenuation method where the relation

$$V = V_o e^{-\alpha X}$$

$$\text{or} \quad I = I_o e^{-\alpha X}$$

holds. It was found that the results were inconsistent and failed to agree with the Current-Voltage method and further use of the method was abandoned.

## APPENDIX C

### Special Precautions

1. It is necessary that the section of line being tested have no metallic connection to other lines, crossovers, etc., which would permit current entry by any means other than through the coating.

2. Tests should not be attempted on lines which are electrically protected with sacrificial anodes spaced at close intervals unless they are disconnected.

3. Tests can be made by imposing a test current on "top of" an existing electrical protection current, provided the test is made entirely within the influence of the protective current being drained to a single point.


# Technical Material Scheduled for Publication

## August Issue:

**Corrosion Studies of Iron in the Presence of Sulfur.**
By Raymond B. Seymour, Walter R. Pascoe and R. B. Stout

**Stainless Steels for the Bottoms of Tanks Containing Sour Crude Oil.**
By C. P. Larrabee and W. F. Rogers

**Control of Corrosion Damage to Rolling Stock Through Proper Design and Maintenance.**
By F. K. Mitchell

**Materials of Construction for Handling Sulfuric Acid. (TP Report)**
By S. W. Shepard

**High Pressure Sweet Oil Well Corrosion.**
By H. L. Bilhartz

## September Issue:

**Dicyclohexylammonium Nitrite, A Volatile Corrosion Inhibitor for Corrosion Preventive Packaging.**
By A. Wachter, T. Skei and N. Stillman

**Prevention of Corrosion and Metal Attack in the Steam Water Cycle of the Steam Power Plant.**
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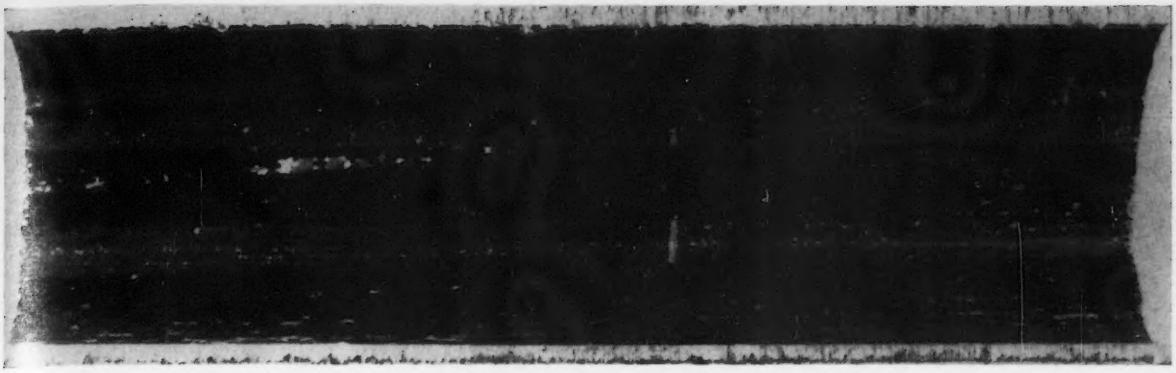


Figure 1—Inside surface of an aluminum brass tube showing outstanding corrosion-resistance towards polluted river water at a Northeastern plant. This aluminum brass contained no dezincification inhibitor and, after 13 years of service, showed no signs of dezincification. This tube is typical of thousands of other tubes in this particular condenser. The loss in wall thickness is less than 0.001 inch or less than 0.00008 inches per yard. The metal surface was covered with a dark reddish-brown film of iron compounds deposited by the river water. The water was chlorinated daily for 20 minutes by injecting sodium hypochlorite solution at low velocity. The appearance and service is typical for an aluminum brass tube kept free from slime by carefully scheduled dosages of chlorine and periodic cleaning. This shows that an alloy which inherently has good corrosion-resistance to flowing water and yet in this instance having susceptibility towards dezincification, is not susceptible to dezincification when kept clean.

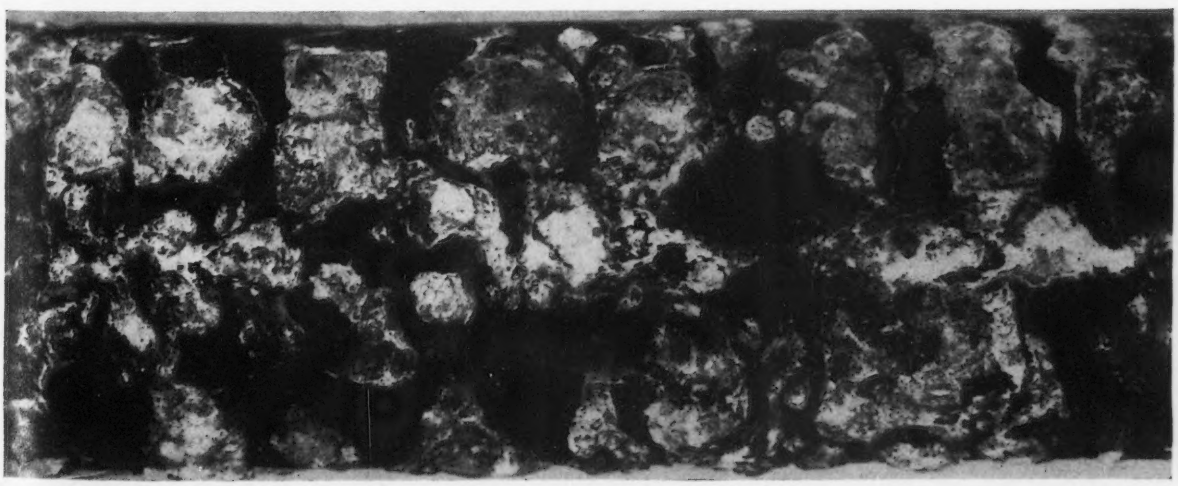
*Topic of the Month*

# Dezincification of Aluminum Brass Condenser Tubes Prevented by Chlorination and Cleaning

*By C. L. BULOW*

Corrosion Metallurgist, Bridgeport Brass Co., Bridgeport, Conn.

Figure 2—An aluminum brass condenser tube of the same composition (also contained no dezincification inhibitor) which, however, failed from plug type dezincification after nine years' service at a Southeastern plant. Brackish river water polluted with paper mill wastes, flowed through this tube. Chlorination of the cooling water used at this plant was not started until three years after these tubes were installed. The difference in performance of the aluminum brass condenser tubing at these two plants is obviously due to the dissimilarity in operating conditions. These dezincified brass tubes have been replaced with arsenical aluminum brass tubes made to ASTM specification B-111, Grade "B". Greatly improved performance is anticipated at this plant through the use of inhibited aluminum brass condenser tubes and scheduled chlorination and cleaning.



NACE News

# Tentative Program Is Outlined for Corpus Christi

## New Officers Are Elected By Pittsburgh Section

New officers were elected as follows at the June 7 meeting of Pittsburgh Section: J. M. Bialosky, United States Steel Co., chairman; N. P. Peifer, Manufacturers Light & Heat Co., vice-chairman. Reelected were W. W. Ringer, Aluminum Company of America, and Frank Costanzo, secretary, Manufacturers Light & Heat Co.

V. V. Kendall presented a paper, "The Application of Mathematical Statistics to Corrosion Problems," in which he described various types of statistical methods that may be applied to corrosion data and illustrated his talk with case histories of proved statistical methods.

The "Manhattan Spotlight" film featuring H. L. Hamilton was shown. The meeting ended with a snack session.

## North Central Region Approves Two Charters

Petitions for charters as sections of the National Association of Corrosion Engineers have been approved by officers of North Central Region for Milwaukee, Detroit and Southwestern Ohio Sections. The signed and approved charters have been sent to A. B. Campbell, executive secretary of the association for action.

Everett C. Gosnell, region chairman, has indicated efforts are under way to form new sections at Indianapolis, Midland and Minneapolis.

Initially Milwaukee Section is authorized to consider Wisconsin as boundary of its section area. This may be restricted later when additional sections are formed. The boundaries of Detroit and Southwestern Ohio Sections are to be fixed.

All sections have under consideration the adoption of constitutions and by-laws and election of officers.

## J. W. YELDELL

J. W. Yeldell, South East Region chairman in 1950 was fatally injured when he fell from his twelfth floor office window at Birmingham, Ala., shortly after noon on May 21. He was vice president of Southern Natural Gas Company, Birmingham.

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Corrosion mitigation processes and materials are publicized free of charge in CORROSION's "New Products" section. NACE accepts no responsibility for accuracy of performance claims.

## Technical Sessions, Plant Trips, Social Events Are Proposed for Regional Meeting

A proposed program for the October 17-20 annual meeting of South Central Region at Corpus Christi, Texas, has been prepared and issued by George A. Mills, general chairman of the meeting. While the program is still in process of organization, the essential elements have been included.

Principal items on the technical program include Technical Practices Committee meetings on Wednesday, October 17, and technical sessions mornings and afternoons on Thursday and Friday, October 18 and 19. Inspection trips have been planned for the afternoon of October 18.

### Social Events Planned

Numerous social events have been projected. A luncheon on October 18 will be followed by a general business meeting of the region. A chartered boat ride on Nueces Bay is also planned to begin at 8 p.m. on that date.

A fellowship hour and seafood dinner is scheduled for the evening of October 19, and a sight-seeing trip and barbecue on King ranch is the principal item on the program for the morning of Saturday, October 20. On this day it is anticipated recognition may be given of the organization of a student section of NACE at Texas Agricultural and Industrial College.

Those attending the meeting who wish to do so may take the opportunity visit Matamoros, Reynosa or Nuevo Laredo, Mexico, distant 120 miles from King ranch.

Entertainment will be provided for visiting ladies.

### Papers Planned

Papers have been proposed so far from Shreveport, Corpus Christi and Houston Sections. Other sections in the region will be asked to make contributions.

Possible inspection and field trips may be arranged to the Corn Products Refining Co. plant, Naval Air Station, American Smelting So., Southern Alkali Co., Celanese Corp. plant at Bishop; Central Power and Light, which uses Gulf water for condensing steam, and several oil refineries and allied oil and gas facilities.

### Committees Named

Committees have been named as follows:

General arrangements: B. P. Ledbetter, chairman; T. F. P. Kelly, M. C. Fleming, George A. Mills, H. E. Waldrip.

Technical program: Derk Holsteyn, chairman; section program chairmen, members.

Local arrangements: Fred C. Reeb, chairman; Fred W. Hodson, co-chairman.

Entertainment: Fred W. Hodson, chairman; Fred C. Reeb, co-chairman.

Ladies entertainment: Mdms. Moffett, Nee, Ward, Mills, Ledbetter and Rankin.

Transportation: J. A. Huckleberry, chairman; Hugh Wilbanks, Jr., co-chairman.

Inspection and field trips: Hugh Wilbanks, Jr., chairman; S. A. Huckleberry, co-chairman.

Registration: A. J. Weist, assistant manager, Robert Driscoll Hotel.

### NACE MEMBERS CHANGING STATUS

**Notification to Central Office NACE of changes of membership status, including changes of address should be made *personally* by the member.**

**NACE is reluctant to make changes in membership records except *when asked to do so by members themselves.***

**Please note also:**

1. **Active and junior memberships are *non-transferable*, because applications are signed personally by members, therefore**
2. **All persons wishing to become members of NACE must submit and *sign personally* an application containing a concise statement of qualifications and including the names of two NACE members in good standing as references.**

## Southwestern Ohio New Officers Named

Permanent officers were elected as follows May 28 at a dinner meeting held at Shuller's Restaurant, Reading, Ohio: Joseph A. Creevy, Newport Steel Corp., chairman; Roy O. McDuffiem, University of Cincinnati, vice-chairman, and Lewis M. Lederer, Inner-Tank Lining Co., secretary-treasurer. Directors were named as follows: Arthur Caster, Walter A. Luce, V. V. Malcom and William Pfieffer.

"Underground Pipe Corrosion in the Petroleum and Natural Gas Services," an address by Joseph A. Creevy, was the featured technical item on the program.

Next meeting is scheduled June 26 at Hartwell Country Club, Cincinnati.

## Chicago and St. Louis Elect New Officers

New Officers were elected by Chicago Section for 1951-52 at a May 15 meeting. They are Franklin M. Watkins, chairman, Sinclair Research Lab., Harvey, Ill.; C. A. Van Natta, vice-chairman, Plastic Lining Corp., Chicago; Laurie E. Nicholls, secretary, Public Service Company of Northern Illinois, Oak Park, Ill., and H. L. O'Brien, treasurer, Graver Tank Mfg. Co., East Chicago, Ind.

New officers for 1951-52 have been elected as follows by Greater St. Louis Section: George A. Fisher, Jr., chairman, The International Nickel Co., Inc., St. Louis; W. F. Gross, vice-chairman, The Tret-O-Lite Company, St. Louis; W. H. Keller, secretary, Johns-Manville Sales Corp., and George E. Purdy, treasurer, all of St. Louis.

Board members elected were R. E. Duce, P. S. Neuhoff, and C. A. Bester. R. D. Sanford has a year's service remaining as board member as a result of his election to fill an unexpired term and F. L. Whitney, Jr., as past chairman, automatically is a member for one year.

## Sea Horse Institute Is Attended by 250

About 250 persons attended the 1951 Informal Conference of the Sea Horse Institute at Wrightsville Beach, North Carolina, May 23-25. The program consisted of discussions of numerous miscellaneous topics related to corrosion in sea water on the afternoons of May 23 and 25 and the following: May 23—Cavitation Erosion; May 24—Effects of Mill Scale and Welding and Protective Coatings; May 25—Cathodic Protection.

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Photographs showing interesting corrosion problems, conditions or solutions of corrosion problems are welcomed for consideration as subjects for the cover illustration of CORROSION magazine. Photographs submitted should be accompanied by an adequate description and the necessary authority to use the photograph.

***Corrosion News Deadline:* 10th of Month *PRECEDING* Date of Issue**

## Chattanooga Meeting of South East Region Is Attended by 40

About 40 members and guests attended the May 9 South East Region meeting at Patten Hotel, Chattanooga, Tenn. The program consisted of two papers, "Protective Coatings," by A. B. Smith, District Manager, Amercoat Corp., Jacksonville, Fla., and "Cathodic Protection," by N. P. Peifer, Corrosion Engineer, Manufacturer's Light and Heat Co., Pittsburgh, Pa. An open forum was held, followed by a fellowship hour.

Dinner speaker was N. E. Berry, NACE president, whose topic was "Basic Factors in Corrosion."

## South Central Chairman Retires on June 15

George A. Mills, South Central Region chairman, who retired from Central Power and Light Company, Corpus Christi, on June 15, will be replaced as soon as region trustees reach an agreement on a successor, Regional Director T. P. F. Kelly said June 7.

Mr. Mills, who also is general chairman for the 1951 Regional meeting to be held at Corpus Christi in October, expects to remove to Dixon, Illinois. He has asked the region trustees to consider what effect his absence will have on arrangements for the annual meeting.

Persons wishing to submit answers to questions asked under the column heading "Corrosion Problems" are requested to send duplicate copies of their answers to Central Office, NACE, 919 Milam Building, Houston 2, Texas. Names of persons submitting replies will be omitted on request.


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Reports of meetings of subdivisions of NACE should be sent to Central Office in sufficient time to meet the publication deadline of the tenth of the month preceding date of issue.


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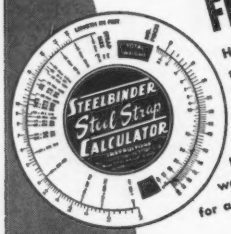


Handy calculator—one side tells you which strap to use for any given corrosive condition; the other side determines length and weight of strap required for any binding operation.

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## North Texas Section Selects New Officers

New officers were elected at the regular April meeting of North Texas Section for the period May-December 1951 at the end of which time the section will consider the advisability of changing the tenure of officers to the calendar year.

Officers elected were: H. L. Bilhartz, chairman, Atlantic Refining Co.; J. C. Spaulding, Jr., vice-chairman, Sun Oil Co.; and N. P. Chesnutt, Southern Union Gas Co., all of Dallas.

## Corpus Christi Hears Talk on Coatings

Nine members and 20 guests of Corpus Christi Section heard an address by L. F. Bramble, president of Gulf State Asphalt Company, South Houston, Texas, on asphalt coatings and participated in a lengthy discussion May 23 at Princess Louise Hotel, Corpus Christi. Mr. Bramble's address was entitled "Asphalt Coatings for Pipeline and Surface Protection."

## AIChE Meetings

Meetings have been scheduled by the American Institute of Chemical Engineers as follows:

1951—Sept. 16-19, Rochester, N. Y., regional; Dec. 2-5, Atlantic City, N. J., national.

1952—March 16-19, Atlanta, Ga., regional; May 11-14, French Lick, Ind., regional; Sept. 4-6, Chicago, regional; Dec. 7-10, Cleveland, Ohio, annual.

## Two Talks on Paint Heard at Los Angeles

Two talks on paints were the featured technical items at an April 18 dinner meeting of Los Angeles Section at Rodger Young Auditorium. There were present 45 members and 12 guests. J. C. McFerran of Old Colony Paint Co. spoke on "Building a Paint Formula," and Joe Taylor of National Lead Co. spoke on "Modern Metal Protective Paints and Practices."

New officers were inducted. Mr. Douglass, newly-elected chairman, was unable to be present. Vance N. Jenkins, NACE past president, gave a report on the national conference in New York.

## Applications Are Sought For Fulbright Awards

Application for Fulbright Awards for 1952-53 effective for the academic year beginning in the autumn of 1952 and covering approximately 230 awards must be received before October 15, 1951, by Executive Secretary, Committee on International Exchange of Persons, Conference Board of Associated Research Councils, 2101 Constitution Ave., Washington, D. C.

For university lecturing and advanced research, in education, the humanities, natural sciences and social sciences, the funds are derived from government grants under auspices of the Department of State and the Board of Foreign Scholarships.

## BOOK REVIEWS

SYMPOSIUM ON CORROSION OF MATERIALS AT ELEVATED TEMPERATURES. American Society for Testing Materials. STP 108. 128 pages, 6 x 9 inches, heavy paper cover. ASTM, 1916 Race St., Philadelphia 3, Pa. Per copy.....$2.25

Contains papers sponsored by Gas Turbine Panel of ASTM-ASEM Joint Committee on the Effect of Temperature on the Properties of Metals. Papers included are: Coal Ash Corrosion of Metals at Elevated Temperatures, Stress-Corrosion Tests on Turbo-Supercharger Materials in the Products of Combustion of Leaded Gasoline, Creep as a Surface Dependent Phenomenon, The Effect of Environment on the Stress-Rupture Properties of Metals at Elevated Temperatures, Preliminary Studies on the Effect of Oxidizing Sulphurous Atmospheres on the Rupture Strengths of Inconel "X" and Inconel, Hydrogenizing Effect of Steam on Ferrous Alloys at Elevated Temperatures, Oil Ash Corrosion of Materials at Elevated Temperatures and The Growing Role of Protective Coatings for Metals in High Temperature Service.

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Notices of meetings to be held by NACE subdivisions will be carried in the "NACE Calendar" if received in time.

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The equivalent of distilled water, with a mineral content of less than 10 ppm—a 96% reduction—is flowing from the all-Monel de-ionizing system at the Swansboro Ice Company, Swansboro, North Carolina.

This equipment operates on the two-stage cation- and acid-removing principle. In the first stage, mineral salts are converted to their equivalent acids by exchanging the original cations for hydrogen ions. The second stage removes the entire acid molecule, leaving the effluent water free from the original dissolved solids.

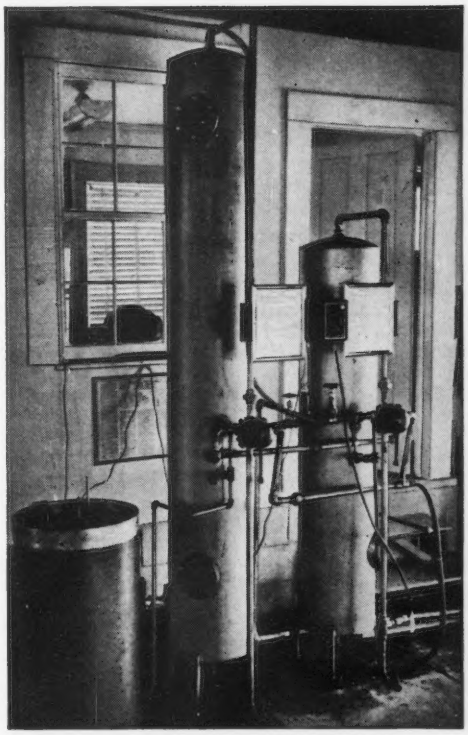
This is the only process, other than distillation, which removes all ions from water. But since such high purity water is obtained by de-ionization, even a trace of metal pick-up can seriously alter the final purity.

Therefore, metal equipment used must be virtually inert to the water carried through it. For several years, piping and fittings of Monel had been used in de-ionization, but it was not realized that entire units could be made of Monel. Then, with the Swansboro installation, it was proved that Monel's resistance to water was so high that metal pick-up from it would affect water purity negligibly, if at all.

***After the equipment had been in use for an entire summer, producing 500 gallons of de-ionized water an hour, the fabricator, Hungerford & Terry, Inc., of Clayton, New Jersey, reported that there had been no detectable metal pick-up from the Monel surfaces.***

If you have a high-purity problem, here is a practical suggestion:

Write INCO's Corrosion Engineering Service, outlining the problem. They will be glad to suggest materials that will help you—either for immediate defense requirements or for future installations.



This all-Monel de-ionization unit, in service at Swansboro Ice Company, Swansboro, N. C., reduces the mineral content of well water from 250 ppm to 10 ppm, with flow of 500 gallons an hour. The entire unit is Monel, except the side tanks containing regenerating materials—yet after a full summer's operation, there had been no detectable metal pick-up, according to the fabricator, Hungerford & Terry, Inc., Clayton, N. J.

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## ASM New Officers Nominated for 1951-52

The nominating committee of the American Society for Metals has named the following to serve as officers for the 1951-52 term: President: John Chipman, head, Dept. of Metallurgy, Massachusetts Institute of Technology. Vice-President: Ralph L. Wilson, Director of Metallurgy, Timken Steel and Tubes Division. Treasurer: Ralph L. Dowdell, head, Dept. of Metallurgy, University of Minnesota. Two new trustees were named: George A. Roberts, Chief Metallurgist, Vanadium-Alloys Steel Corp., and J. B. Johnson, Chief of Materials Division, Wright-Patterson Air Force Base, Dayton, Ohio.

## Chemical Plant Symposium

"Chemical Plant Maintenance" will be the topic of one of three symposia to be held during a regional meeting of the American Institute of Chemical Engineers at Rochester, N. Y., September 17-19. Registration chairman is Earl W. Costich, 417 Crossfield Road, Rochester, N. Y.

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Photographs showing interesting corrosion problems, conditions or solutions of corrosion problems are welcomed for consideration as subjects for the cover illustration of CORROSION magazine Photographs submitted should be accompanied by an adequate description and the necessary authority to use the photograph.

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# Corrosion Problems

**E. A. TICE, Editor**

**Corrosion Engineering Section, The International Nickel Co., Inc., 67 Wall St., New York 5, N. Y.**

**Submit questions and answers for this column in duplicate to the editor. All questions become property of NACE. Questions and Answers may or may not be published under this heading, and may at discretion, be answered by mail directly. Answers to questions are solicited. Authors of questions will remain anonymous to readers while authors of answers may remain anonymous if they request it.**

### QUESTION

No. 21—What is the reaction between aluminum (sheets) and 31% formaldehyde solution that causes pitting?

### ANSWER

**Our experience with formaldehyde in aluminum has been chiefly with 3S and 61S in the form of welded and seamless piping and welded plate at temperatures below 160° F.**

**It is believed that the cause of corrosion of the aluminum is the formic acid contained in the formaldehyde. This will react with the aluminum forming aluminum formate which can decompose further to form aluminum oxide.**

**We have noted that pitting of varying depths occurred in most of our aluminum equipment within a short period after installation, but that after a longer period the attack appeared to be self-limiting. Some of the piping in which pitting was noted after six months service is still in service after five years and no evidence of further attack can be found.**

**It is believed that the formic acid penetrates the protective oxide film on the aluminum allowing concentration cells to be set up and pitting to progress. As the corrosion product is formed it protects the material in this specific location from further action of the formic acid thus causing the area to cease functioning as an anode.**

**The above theory is believed to be sound under usual flow conditions. However other conditions such as intermittent flow, paraform formation, temperature and pressure variations, as well as intermittent admittance of air to the system, may have a definite effect.—By R. C. Schueler, Metallurgist, Celanese Corporation of America, Bishop, Texas.**

### QUESTION

No. 37—What material, or materials, can be used for a tank, pipe line, pump and valves to handle 98 percent sulfuric acid at 150°F, unaerated? Maximum velocity through a three-inch line would be two feet per second.

### ANSWER

**I believe the following materials will serve best for handling the sulfuric acid under the conditions outlined:**

1. **Tank—Steel, brick lined.**
2. **Pipe—Cast iron, flanged, using asbestos millboard or hard finished asbestos sheet gaskets.**
3. **Pump—Cast iron, Centrifugal or Worthite or equivalent.**
4. **Valves—"Aloyco 20," gate valve Teflon packed.**

**I believe the above materials will last reasonably well since we have used them under similar conditions for a long period of time.—By C. M. Hickey, General Superintendent, Consolidated Chemical Industries, Southern Division.**

### QUESTION

No. 44—In cathodic protection of tank bottoms on a petroleum tank farm, would not small individual rectifiers for each tank give more economical and positive protection than larger units protecting a number of tank bottoms?

### ANSWER

**The problem resolves itself to economics. Since no data regarding to size of tank bottoms, the physical layout, soil conditions, uncoated or coated shell, an answer is difficult to give. Well designed cathodic protection units either large or small should afford protection. One will find that 4 to 6 tank bottoms are protected from soil corrosion by only one unit, or when more economical, individual tank bottoms are protected with galvanic anodes. — By Derk Holsteyn, P. O. Box 2527, Houston, Texas.**

### QUESTION

No. 46—In the chemical industry what use has been made of cathodic protection, particularly by impressed current, in overcoming corrosion problems in processing equipment?

### ANSWER

**We have had considerable experience with cathodic protection of processing equipment, although none of it has been by impressed current. All types of equipment handling sea water, such as rotary screens, tanks, condenser boxes, and large transfer lines, are being successfully cathodically protected with magnesium anodes. In addition salt brine tanks and other equipment, handling high conductivity solutions where the pH is above 5.5, are being protected in a similar fashion. Detailed discussion of these applications can be found in our paper "Combating Corrosion in a Chemical Plant with Magnesium Anodes" in the January, 1951, issue of "Corrosion."—By Oliver Osborn, The Dow Chemical Company, Freeport, Texas.**

### NEW QUESTIONS

No. 87—What is the probable cause of pitting a few inches from seams of AISI type 316 Cb stainless clad steel in sulfite digestors?

No. 88—What types of soil and metal are most corrosive to lead-covered cables in metal conduit?

No. 89—Is the chemical purity of zinc anodes for sacrificial protection of steel critical, and if so, what are some of the boundary limits for content of impurities? If secondary zinc metal is suitable, what impurity has the most influence on effective performance of the anode?

**MEMBERSHIP CARDS AVAILABLE**

**Association members in good standing will be issued on request a membership card in the National Association of Corrosion Engineers. Address requests to A. B. Campbell, Executive Secretary, 919 Milam Building, Houston 2, Texas.**

# SOMASTIC★

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**20 YEARS** is a long time on the job, preventing corrosion damage to underground pipe. SOMASTIC Pipe Coating has furnished complete protection at severely corrosive locations since its first year—1930.

In fact, our knowledge of its useful life is limited only by the total time it has been in existence.

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**2 ECONOMICAL METHODS OF APPLICATION:**

*... by Central Plant*

*... by portable Railhead Plant*

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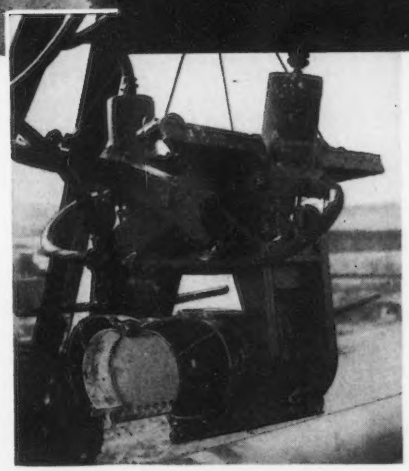
**The sure protection of impervious asphalt-mastic—won't distort under soil stresses; resists shock; prevents electrolysis. Ductile; inert; firmly bonded to pipe.**

**RAILHEAD PLANT.** Choice between railhead and central plant depends on the economics of a specific job.



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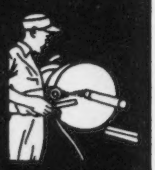
## TP-5B Chairman

W. W. Sweet, Materials of Engineering Div., Colgate-Palmolive Peet Co., Jersey City, N. J., has been named chairman of Technical Practices Subcommittee 5B—Design of Equipment for Corrosive Services.


**METAL SPRAYING**



Metallized Coatings applied in our plant or in the field to protect tanks, ducts, structural steel, ships, bridges and tank cars, against corrosion and or contamination. Metallizing to build-up crankshafts, cylinder, pistons, bearings, rams, rolls, etc.

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## Sound Films Available From Westinghouse

A 14-minute sound film featuring H. L. Hamilton, North East Region chairman, explaining many phases of corrosion, is available for use at NACE meetings, L. B. Donovan, director of North East Region, announces. The film is a copy of the program telecast over the DuMont network March 9 at New York City. Those interested in showing this film may communicate directly with Mr. Donovan.

Westinghouse Electric Corp. offers for use by organized groups for the cost of transportation both ways, 72 16-mm. sound films of the firm's activities and products. The films are described in a catalog, Booklet B-4746, copies of which may be secured by writing Westinghouse Electric Corp., Box 2099, Pittsburgh 30, Pa.

## Diffraction Conference Scheduled for November

Sessions on Instrumentation and Methods and Metals and Alloys have been arranged tentatively for the Ninth Annual Pittsburgh Diffraction Conference at Mellon Institute, November 29 and 30, 1951. Papers on these and related subjects are solicited, and will be considered in the order in which received. Titles should be sent to the program chairman, R. W. Turner, Carnegie Institute of Technology, Pittsburgh 13, Pa., before September 1.

The conference will include also a symposium of invited papers on the subject Diffraction and Thermomagnetic Studies of Reactions of Metastable Carbides of Iron.

Further information and a copy of the preliminary program when available may be secured from C. W. Cline, Aluminum Research Laboratories, P. O. Box 772, New Kensington, Pa.


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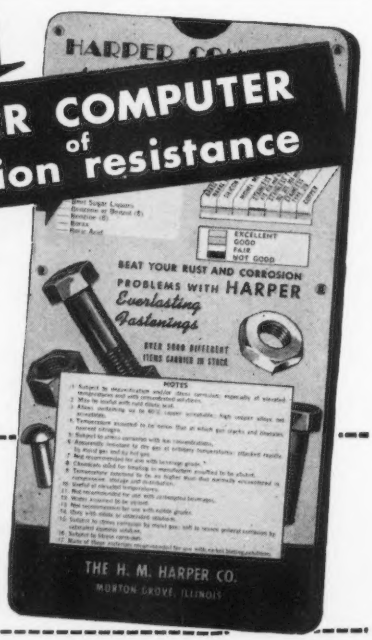


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## NACE

### New Members and Changes of Address

- This list is published principally for use by NACE Regional and Sectional officers in keeping their mailing lists up to date.

**(Changes through May 29, 1951)**

**ARKANSAS**

SMITH, C. W., Crossett Paper Mills, Crossett, Ark.

**CALIFORNIA**

AXLUND, RAYMOND A., 519 Napa St., Apt. C., Vallejo, Cal.
WAKEFIELD, CLARENCE N., JR., Amercoat Corp., 4809 Firestone Blvd., Southgate, Cal.
WARREN, SAM M., Liquid Plastics Co. of Cal., 640 Broad Ave., Wilmington, Cal.

**CONNECTICUT**

RICE, GERALD B., The Bassick Co., 237 Howard Ave., Bridgeport, Conn.

**DELAWARE**

CARROW, JOHN W., III., 6 Court Dr., Lancaster Court, Wilmington, Del.
SHANKWEILER, FRED K., Hercules Powder Co., 9th & Market St., Wilmington, Del.

**FLORIDA**

CARTER, JOHN, Chief Engineer, Signal Bureau, 1066 Laura St., Jacksonville, Fla.
THOMPSON, THOMAS F., JR., Florida Power Corp., P. O. Box 4042, St. Petersburg, Fla.

**ILLINOIS**

BAUER, CONRAD A., Commonwealth Edison Co., 72 W. Adams, Chicago 90, Ill.
KIEFER, JAMES M., Armour & Co., Research Div., 1355 W. 31st St., Chicago 9, Ill.
ROSE, W. T., Commonwealth Edison Co., 72 West Adams, Chicago, Ill.
SCHMUCK, G. GORDON, Perma-Line Rubber Products Corp., 1755 N. Winnebago St., Chicago 47, Ill.

**KANSAS**

STORER, ALTON B., The Marley Co., Inc., 3001 Fairfax Rd., Kansas City, Kan.
WRIGHT, PRESTON C., Servisoft Soft Water Service, P. O. Box 221, Arkansas City, Kan.

**LOUISIANA**

HARPER, GEORGE M., JR., Union Oil Co. of California, Box 421, Abbeville, La.
MARQUEZ, EDWARD B., 104 Maryland Dr., New Orleans, La.

**MASSACHUSETTS**

GLOVER, MANSON, Glover Coating Co., Inc., 376 Washingtn St., Malden 48, Mass.
WEY, GEORGE L., Port of Boston Authority, Commonwealth Pier No. 5, South Boston, Mass.

**MICHIGAN**

IVANSO, EUGENE V., Steel Sales Corp., 5151 Wesson Ave., Detroit, Mich.

**MINNESOTA**

FORDERBRUGEN, KEVIN J., Minnesota Valley Natural Gas Co., St. Peter, Minn.
WILLIS, STANLEY J., Spark-O-Liner Corp., 601 11th Ave., South. Minneapolis, Minn.

**MISSISSIPPI**

WALTER, VICTOR A., JR., The California Co., Box 360, Natchez, Miss.

**MISSOURI**

GARLOCK, NEIL B., The Eagle-Picher Co., Box 290, Joplin, Mo.

**NEW JERSEY**

BELMORE, ALBERT B., Prufcoat Laboratories, Inc., 155 Fern Ave., Collingswood, N. J.
EPSTEIN, LEONARD, Stevens Institute of Tech., Castle Point, Hoboken, N. J.
KENNISON, HUGH F., Lock Joint Pipe Co., P. O. Box 269, East Orange, N. J.
McGRATH, MARTIN H., General Cable Corp., 26 Washington, Perth Amboy, N. J.
SCHNEIDER, FREDERICK W., Colgate-Palmolive-Peet Co., 105 Hudson St., Jersey City, N. J.
SEAMAN, E. EUGENE, Lock Joint Pipe Co., P. O. Box H, Wharton, N. J.
STEPHENS, WILLIAM H., Rexton Finishes, Inc., 62 Woolsey St., Irvington 11, N. J.
STRAIN, MARRETTE, Continental Paper Co., Industrial Ave., Ridgefield Park, N. J.

(Continued on Page 10)

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| **Lincoln Pk. 25 (Detroit), Mich.**<br>**DIX ENGINEERING CO., INC.**<br>1417 Dix Road<br>Tel. Dunkirk 1-8822 | **Philadelphia 29, Pa.**<br>**METALWELD, INC.**<br>Fox & Hunting Park Ave.<br>Tel. Radcliff 5-3471 | **St. Louis, Missouri**<br>**NOOTER CORPORATION**<br>1420 South Second Street<br>Tel. Main 6000 | **Brooklyn, N. Y.**<br>**ARTHUR TICKLE ENGINEERING WORKS, INC.**<br>21 Delevan Street<br>Tel. Main 5-4200 | **Houston, Texas**<br>**F. W. GARTNER CO.**<br>3805 Lamar Avenue<br>Tel. Atwood 5338 |

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## New Members—

(Continued From Page 8)

SWEET, WARREN W., Colgate-Palmolive-Peet Co., Res. & Dev. Dept., 105 Hudson St., Jersey City 2, N. J.

### NEW YORK

BANKS, J. A. DAVIS, American Hard Rubber Co., 11 Mercer St., New York 13, N. Y.
DAW, RONALD F., The Texas Company, 135 East 42nd St., New York 17, N. Y.
DYKMAN, MILTON, Mixing Equipment Co., 135 Mt. Read Blvd., Rochester, N. Y.
GILLAN, HOWARD J., Haverstick & Co., Inc., P. O. Box 116, Rochester, N. Y.
HANSEN, EUGENE R., 8025 Capitol St., Houston 11, Texas.
McKIRRYHER, MARTIN J., C. Raymond Ahrens, Inc., 30 Church St., New York 7, N. Y.
MULCAIR, JEREMIAH, J., 205 East 83rd St., New York, N. Y.
NOSS, OSCAR F., Fitzgibbons Boiler Co., Inc., 101 Park Ave., New York, N. Y.
POLEN, LEWIS B., Allegheny Ludlum Steel Corp., 3445 River Rd., Box 12, Station B, Buffalo 7, N. Y.
RICE, EDWARD F. T., General Aniline Works, Riverside Ave., Rensselaer, N. Y.
ROBINSON, HENRY B., The Debevoise Co., 74-84 20th St., Brooklyn 32, N. Y.
SCHIFFER, JACQUES M., Nocon Products Corp., 62 William, New York 5, N. Y.
TOOMEY, JOSEPH C., Insul-Mastic Co. of Rochester, 101 N. Lincoln Rd., East Rochester, N. Y.
TUCKER, SYDNEY, Fitzgibbons Boiler Co., Inc., Oswego, N. Y.

### OHIO

BAKER, RALPH D., 1925 Park Place, Dayton 6, Ohio.
COMPTON, MARYANN, Cincinnati Milling Machine Co., Products Div., Marburg & Disney, Cincinnati 9, Ohio.
EBERLE, F., The Babcock & Wilcox Co., Res. & Dev. Dept., Harrisburg & Sawburg Roads, Alliance, Ohio.
SHERMAN, CHARLES H., The C. P. Hall Co., 2510 First National Tower, Akron, Ohio.
WILLIAMS, JOSEPHINE L., Cincinnati Milling Machine Co., Products Div., Marburg & Disney, Cincinnati 9, Ohio.

### OKLAHOMA

FULLERTON, F. W., S. W. Bell Telephone Co., 405 N. Broadway, Oklahoma City, Okla.
GOODSON, LOYD, Oklahoma Natural Gas Co., 213 N. Broadway, Shawnee, Okla.
JOHNSTON, JOHN E., Oklahoma Natural Gas Co., P. O. Box 1620, Oklahoma City, Okla.
McDERMOTT, BYRON, Southwestern Bell Telephone Co., 1101 Telephone Bldg., Oklahoma City, Okla.
MINNICK, ARVEL L., Oklahoma Natural Gas Co., 213 N. Broadway, Shawnee, Okla.
OWEN, BRUCE D., 2625 N. W. 26th St., Oklahoma City, Okla.
TAYLOR, FRANK S., City of Oklahoma City Water Dept., Municipal Bldg., Oklahoma City, Okla.

### PENNSYLVANIA

COX, MILTON K., Koppers Co., Inc., Koppers Bldg., 7th Ave., Pittsburgh 19, Pa.
CROFT, WILLIAM F., 1002 Riehl Rd., Pittsburgh 34, Pa.
DALE, LAWRENCE H., American Car & Foundry Co., 9th & Oak Sts., Berwick 6, Pa.
DURISHIN, JOHN F., 3225 Lincoln Circle North, Allentown, Pa.
McNAMARA, R. L., Sterling Varnish Co., Haysville, Pa.
MIXER, RICHARD A., Metalweld, Inc., 2617 Hunting Park Ave., Philadelphia 29, Pa.
WILLIAMSON, P. KENT, Smith Paint Products, 1817 N. Cameron, Harrisburg, Pa.

### TEXAS

BOUDREAUX, TRACY P., University Trailer Village, No. 143, University of Houston, Houston 4, Texas.
HAILE, EDWARD L., Monsanto Chemical Co., Box 1311, Texas City, Texas.
HIBLER, MARION Y., Southern Union Gas Co., 401 12th St., Port Arthur, Texas.
HOLTZAPPLE, FRANK R., Phillips Petroleum Co., Drawer 272, Alvin, Texas.
HOWELL, KENNETH S., 829 Columbia, Houston 8, Texas.
LAENGER, RALPH E., Union Producing Co., Box 711, Beeville, Texas.
MARTIN, JAMES H., JR., Route 1, Box 181, Baytown, Texas.
PHILLIPS, CARROLL O., Union Producing Co., Chemical Dept., Box 711, Beeville, Texas.
SAYE, HUGH A., JR., Harco Corp., 2001 Harold, Houston 6, Texas.
WALKER, ROBERT B., Magnaflux Corp., 2110 N. Muskingum, Odessa, Texas.
WRIGHT, EDWARD V., JR., Texas A. & M. College, Box 4979, College Station, Texas.
WHITE, HOWARD R., Tennessee Gas Transmission Co., Box 2511, Houston, Texas.

### VIRGINIA

MACIAS-RENDON, FERNANDO, Box 5308, Virginia Tech. Station, Blacksburg, Va.

### WISCONSIN

ANDRUS, ORRIN E., A. O. Smith Corp., 3533 N. 27th St., Milwaukee 1, Wis.
COTTON, WILLIAM J., W. J. Cotton Laboratories, 3530 W. Fairmount Ave., Milwaukee 9, Wis.
HERBST, IRENE A., A. O. Smith Corp., 3533 N. 27th St., Milwaukee, Wis.
JASKI, FRANK E., Allis-Chalmers Mfg. Co., Box 512, Milwaukee 1, Wis.
MACK, DAVID J., University of Wisconsin, Dept. of Mining & Met. Eng., 1509 University Ave., Madison 6, Wis.
PORTER, LEW F., University of Wisconsin, College of Eng., Dept. of Mining & Metallurgy, 1509 University Ave., Madison 6, Wis.
WERNST, JACOB, Chain Belt Co., 1600 W. Bruce, Milwaukee, Wis.
WILSON, RUSHEN A., 3233 S. 21st St., Milwaukee 15, Wis.

### FOREIGN

CORCUERA, ING. FRANCISCO L., Petroleos Mexicanos (Cd. Madero Refinery) Apartado Postal No. 161, Tampico, Mexico.
DAVIES, ALAN T., The Phosphate Co-Operative Co., of Australia, Ltd., 447 Little Collins St., Melbourne, Victoria, Australia.
FLORES, LEOPOLDO N., Petroleos Mexicanos Refineria de C. Madero, Tamps, Mexico.
FUJIMURO, MASUZO, The Nippon Corrosion Enginering Co., Ltd., No. 5, 1-chome, Kanda-Sudacho, Chiyoda-ku, Tokyo, Japan.
KIRWIN, JAMES E., Lago Oil & Transport Co., Ltd., Aruba, Netherlands Antilles.
MURPHY, ARTHUR N., Messrs Costain-John Brown Ltd., 73 S. Audley St., London W. 1., England.

## CHANGES OF ADDRESS

**(Old address follows new in parenthesis)**

### CALIFORNIA

APERULE, CHARLES J., JR., Warren & Bailey Co., 266 7th Ave., San Diego 1, Cal. (350 S. Anderson St., Los Angeles 33, Cal.)
SAUNDERS, WILLIAM F., Pittsburgh Coke & Chemical Co., 612 S. Flower St., Room 746, Los Angeles 17, Cal. (Pittsburgh Coke & Chemical Co., 1720 Grant Bldg., Pittsburgh, Pa.)
SHONAFELT, AUSTIN E., The Norwalk Co., Box 286, Bakersfield, Cal. (The Norwalk Co., Rosedale Highway, Bakersfield, Cal.)
WELLS, C. KENYON, Long Beach Water Dept., 403 Municipal Utilities Bldg., 215 W. Broadway, Long Beach 2, Cal. (Long Beach Water Dept., 403 Municipal Utilities Bldg., 215 W. Broadway, Long Beach 6, Cal.)

### COLORADO

SPARKS, ROBERT E., LCDR, Suite 410, Mining Exchange Bldg., Denver 2, Colo. (U. S. Naval Dept., Room 1046, Bldg. T-3, Washington 25, D. C.)

### GEORGIA

ERGANIAN, ALEX M., Pipe Line Service Corp., 1734 Candler Bldg., Atlanta, Ga. (4101 San Jacinto, P. O. Box 8188, Houston 4, Texas.)

### ILLINOIS

GROVES, KEN D., Ken Groves, Inc., 1763 West 95th, Chicago 43, Ill. (Saunders & Co., 3445 S. Lawndale Ave., Chicago 23, Ill.)
LINDBERG, RAMON I., Sinclair Research Laboratories, Inc., 400 E. Sibley Blvd., Harvey, Ill. (Research & Dev. Dept., Sinclair Refg. Co., 400 E. Sibley Blvd., Harvey, Ill.)
SHELDAHL, DAVID B., Sinclair Research Laboratories, Inc., 400 E. Sibley Blvd., Harvey, Ill. (Sinclair Refining Co., 400 E. Sibley Blvd., Harvey, Ill.)
WATKINS, FRANKLIN M., Sinclair Research Laboratories, Inc., 400 E. Sibley Blvd., Harvey, Ill. (Sinclair Refining Co., 400 E. Sibley Blvd., Harvey, Ill.)

### KANSAS

EVANS, HERSCHEL, Service Pipe Line Co., P. O. Box 519, Topeka, Kan. (Service Pipe Line Co., P. O. Box 591, Scottsbluff, Neb.)
FUNCK, DONALD E., 102 S. Manhattan St., Manhattan, Kan. (1418 Houston St., Manhattan, Kan.)
LADD, GLENN L., Sinclair Pipe Line Co., Box 460, Independence, Kan. (Sinclair Oil & Gas Co., Box 1070, Seminole, Okla.)

### KENTUCKY

STULL, FRED D., Texas Gas Transmission Corp., 401 W. Third St., Owensboro, Ky. (Texas Gas Transmission Co., 931 Sterick Bldg., Memphis 3, Tenn.)

### LOUISIANA

WAMSLEY, PAUL, JR., 1266 Stephens Ave., Baton Rouge, La. (1655 Eugene St., Baton Rouge 6, La.)

(Continued on Page 12)

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## New Members—

(Continued From Page 10)

**MINNESOTA**

HILL, WALLACE T., 706 E. Academy St., Apt. "D," Owatonna, Minn. (524 Marion St., Boone, Iowa.)

**MISSISSIPPI**

AKERBERG, GEORGE E., Route 10, Box 61A, Jackson, Miss. (386 Raymond Rd. Gardens, Apartment 5D, Jackson, Miss.)

LOVELL, ODUS W., JR., United Gas Pipe Line Co., P. O. Box 86, Petal, Miss. (United Gas Pipe Line Co., P. O. Box 1407, Shreveport 92, La.)

**MISSOURI**

SERENCO, HARVEY, Upper Mississippi Valley Div., U. S. Corps of Engr's., P. O. Drawer No. 3, Central Station, St. Louis, Mo. (Upper Mississippi Valley Div., U. S. Corps of Engr's., 755 New Federal Bldg., St. Louis 1, Mo.)

**NEBRASKA**

KRUEGER, JESS J., Northern Natural Gas Co., P. O. Box 1310, Omaha 1, Neb. (Cathodic Supr., Northern Natural Gas Co., 1708 Grant St., Beatrice, Neb.)

**NEW JERSEY**

MATHERS, W. D., 62 Buff Rd., Tenafly, N. J. (643A Bruce St., Ridgefield, N. J.)

**NEW YORK**

BATTLE, THOMAS J., 629 West 115 St., New York 25, N. Y. (Joseph Dixon Crucible Co., Jersey City 3, N. J.)

BRUSH, EDWIN G., Riverside Place, Alplaus, N. Y. (General Electric Co., 342 Dalton Ave., Pittsfield, Mass.)

DE LASKI, ROBERT D., W. A. Briggs Bitumen Co., 30 Church St., 423 E, New York 7, N. Y. (W. A. Briggs Bitumen Co., 30 Church St., New York, N. Y.)

ISAACKS, ALBERT, N., P. O. Box 1293, Syracuse, N. Y. (128 W. Southside Blvd., Independence, Mo.)

LATTIN, BENTON C., 3 Bretton Rd., Scarsdale, N. Y. (LATTIN, BENTON CALVER, Westchester Lighting Co., 9 S. First Ave., Mt. Vernon, N. Y.)

MORAN, JOSEPH H., 56 Greenwood Place, Buffalo 13, N. Y. (265 Hoyt St., Buffalo 13, N. Y.)

**OHIO**

SCHREINER, WILLIAM J., Cincinnati Gas & Electric Co., Fourth & Main Sts., Cincinnati 2, Ohio. (Cincinnati Gas & Electric Co., 323 Plum St., Cincinnati 2, Ohio.)

SEAL, REED E., 2070 East 61st Place, Cleveland 3, Ohio. (Erico Products, Inc., 2070 East 61st Place, Cleveland 3, Ohio.)

**OKLAHOMA**

BRADLEY, BRYANT W., Shell Oil Co., 4520 E. 6th St., Tulsa, Okla. (3222 Elmridge, Houston 21, Texas.)

CARPENTER, DAN H., 5208 N. Hudson, Oklahoma City 6, Okla. (Tretolite Co., Route 1, Box 386, Oklahoma City 11, Okla.)

HANCOCK, CHARLES W., The Pure Oil Co., P. O. Box 288, Nowata, Okla. (The Pure Oil Co., Box 271, Tulsa, Okla.)

PEARD, JAMES C., 1131 E. 37th St., Tulsa, Okla. (Service Pipe Line Co., Box 519, Topeka, Kan.)

**OREGON**

VAN RYSSELBERGHE, PIERRE, Dept. of Chemistry, University of Oregon, Eugene, Ore. (c/o Prof. R. Piontelli, Politecnico di Milano—32 Piazza Leonardo da Vinci, Milano—132—, Italy.)

**PENNSYLVANIA**

MACDONALD, A. JOHN, University of Pittsburgh, 319 De Sota Hall, Pittsburgh 13, Pa. (Gulf Oil Corp., 5311 Kirby Dr., Houston, Texas.)

**TEXAS**

ANDERSON, VICTOR A., 907 20th St., Galveston, Texas. (University of Houston, 3801 Cullen Blvd., Houston, Texas.)

EDWARDS, W. H., c/o The Superior Oil Co., 400 Oil & Gas Bldg., Houston 2, Texas. (5204 Elm St., Bellaire, Texas.)

GOODRICH, C. R., 260 Post Ave., San Antonio 2, Texas. (100 Penn St., Fort Worth, Texas.)

GRIFFITH, DARREL F., 404 W. Goodwin, Apt. 2D, Victoria, Texas. (Tretolite Co., Box 1181, Houman, La.)

HENRY, ERNEST L., P. O. Box 122, Bonham, Texas. (549 College St., Bellaire, Texas.)

KRELL, ABRAHAM J., 6412 Rutger, Houston, Texas. (2303 Wroxton Rd., Houston 5, Texas.)

LEMAY, JACK E., 515 Wilson Bldg., Dallas 1, Texas. (4628 E. Willock Rd., Pittsburgh 27, Pa.)

ORCHARD, E. L., Central Power & Light Co., Laredo Power Station, P. O. Box 997, Laredo, Texas. (Central Power & Light Co., Box 2121, Corpus Christi, Texas.)

RAINEY, JOHN B., The Rainey Co., Box 6125, Houston 6, Texas. (2116 Milford, Houston 6, Texas.)

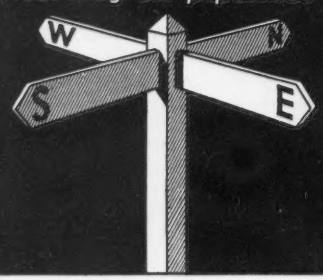
**VIRGINIA**

ROSENTHAL, MORRIS, 930 Manor Rd., Alexandria, Va. (607 Coffin Ave., El Paso, Texas.)

**FOREIGN**

BLANCO, FELIX F., Chiclana 324, Bernal, F.C.N.G.R., Rep. Argentina, S. A. (Independencia 88—Bernal, Prov. de Buenos Aires, Rep. Argentina, S. A.)

"serving all pipelines"




PIPELINE COATINGS
and
WRAPPING MATERIALS

S. D. DAY COMPANY

1973 WEST GRAY HOUSTON, TEXAS PHONE JU-2431

## NEW CORPORATE MEMBERS

THE CARTER OIL COMPANY
Tulsa, Oklahoma
A. T. Clothier, Representative

NORFOLK & WESTERN RAILWAY CO.
Roanoke, Virginia
C. L. Crockett, Representative

WARREN PETROLEUM CORPORATION
Tulsa, Oklahoma
J. A. LaFortune, Representative

Photographs showing interesting corrosion problems, conditions or solutions of corrosion problems are welcomed for consideration as subjects for the cover illustration of CORROSION magazine. Photographs submitted should be accompanied by an adequate description and the necessary authority to use the photograph.

## Clippings on Corrosion

*Extracted from Current Periodicals*

### CORRUGATED ASBESTOS SIDING USES GROWING

(From Casper, Wyo. *Star,* May 20, 1951)

A stone-hard, fireproof building material that will not rot or corrode and which defies rats and termites has become a useful addition to traditional materials. Corrugated asbestos siding is being used especially in landscape applications.

•

### PLAIN LANGUAGE AIDS INQUIRING PLUMBER

(From Warrensburg, Mo. *Star-Journal,* May 21, 1951, taken from Oxford, Ohio *Press)*

A member of the National Bureau of Standards staff, replying to a plumber's inquiry about the desirability of using hydrochloric acid as a drain cleaner, wrote: "The efficiency of hydrochloric acid is undisputable, but the corrosive residue is incompatible with metallic performance." The plumber wrote back thanking the bureau for telling him his method was okay. Dismayed, the bureau again wrote the plumber: "We cannot assume responsibility for the production of toxic and noxious residue with hydrochloric acid and suggest you use an alternative procedure."

The plumber again thanked the bureau for saying his method was alright.

The scientists closed the file finally by writing the plumber: "Don't use hydrochloric acid. It eats hell out of the pipes."

•

### PROTECT METAL FURNITURE

(From Wellsville, N. Y. *Reporter,* May 29, 1951)

Metal porch furniture should be protected from corrosion by an application of wax.

•

### RENOVATING AIR BASE TO COST $12,000,000

(From Ogallala, Neb. *News,* Apr. 30, 1951)

Part of the $12,000,000 estimated cost of renovating the U. S. Naval Training Station, now Sampson Air Force Base in New York is to replace corroded heating and water pipes. Cost of renovating buildings is much higher proportionately than original construction cost, Irving Lichtman, chief project engineer, said.

•

### SUMMER CARE OF HOME HEATING PLANTS URGED

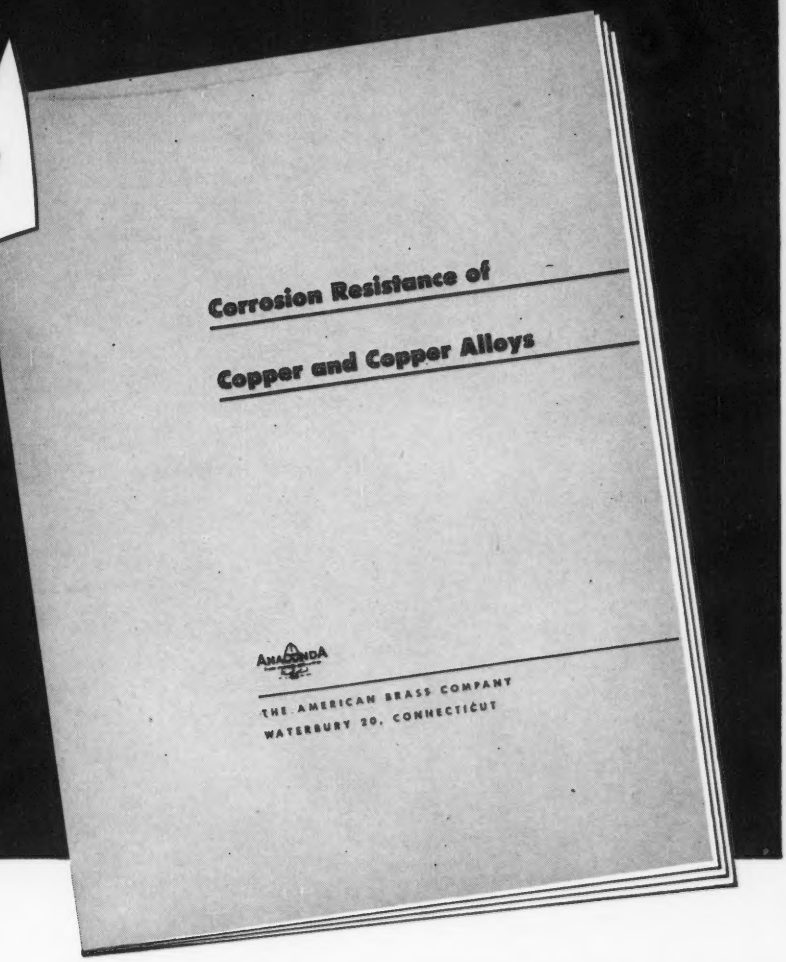
(From Louisville, Ky. *Times,* May 3, 1951)

Removal of soot from home heating plants before shutting them down for the summer will prevent corrosion of the smoke pipe, which otherwise is attacked by sulfuric acid formed by moisture absorbed by the soot.

# New Corrosion Data!

YOU WILL WANT THIS IMPORTANT BOOKLET

containing a new collection of data on corrosion resistance of copper and copper alloys.




*For operators and designers of:*

**Process Equipment**
**Heat Exchangers**
**Condensers**
**Evaporators**
**Chemical Equipment**
**Waterworks and Sewage Plants**

This new booklet presents in concise, usable form important technical discussions and data on the corrosion resistance of copper and copper alloys. Here are the subjects included:

- **Theory of Corrosion and Types of Corrosive Attack**
- **General Discussion of Corrosion Resistance of Copper Alloys**
- **Corrosion Rating Charts**
- **Typical Industrial Uses of Copper Alloys**
- **Composition, Mechanical and Physical Properties of Copper Alloys**

51198

SEND FOR YOUR FREE COPY TODAY!

**The American Brass Co., Waterbury 20, Conn. (In Canada: Anaconda American Brass Ltd., New Toronto, Ontario.)**

Please send me my copy of your new booklet, "Corrosion Resistance of Copper and Copper Alloys."

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COMPANY.....

STREET.....

CITY.....ZONE.....STATE.....

***where corrosion resistance counts — consider***

**ANACONDA®**
**COPPER AND COPPER ALLOYS**

# NEW PRODUCTS – Materials – Service – Literature

**"B" Resin,** a flexible prepolymerized furan protective coating, is said by manufacturers, the Carboline Co., 7603 Forsythe Blvd., St. Louis 5, Mo., to be superior to rubber base and polyvinyl chloride coatings. It contains no plasticizer to leach out. It possesses the resistance of furan materials to non-oxidizing acids, solvents and alkalis as well as resistance to oxidizing acids and bleaches. Applied as a ready-mixed coating, the material completes polymerization two to four hours after application. It resists such solvents as alcohols and straight chain hydrocarbons at elevated temperatures and chlorinated and aromatic hydrocarbons and glacial acetic acid at room temperatures. Further information including Data Sheet C-33 giving test data on 159 corrosion tests may be had on request.

•

**Porcelain Pipe** and fittings, including pipe and valves are recommended by manufacturers Illinois Electric Porcelain Co., Macomb, Ill. as use for drain lines for battery room wastes, alum lines and for handling other corrosive materials. The firm also makes special shapes to order.

•

**Reference Book** on Instruments, compiled by the Subcommittee on Instrumentation, American Gas Association, under direction of M. C. Miller, chairman of the subcommittee, includes articles dealing with characteristics of electrical instruments for corrosion investigations, high voltage inspection of pipe coatings, location of underground pipe coating faults, and several other types of meters and testing equipment is available on order for $1.50 per copy from American Gas Association, 420 Lexington Ave., New York 17, N. Y.

•

**Petroleum Engineering,** Inc., has removed to 2480 Times Blvd., Houston 5, Texas.

•

**Schedule 5** stainless steel pipe's characteristics are compared with those of standard thickness pipe in a table issued by Carpenter Steel Co., Alloy Tube Div., Union, N. J.

•

**A Guide** of standards designations and chemical composition ranges for heat and corrosion resistant castings issued by Alloy Casting Institute, 32 Third Ave., Mineola, N. Y., lists 27 cast alloy types. Included is a provision for the use of ferro-columbium-tantalum as an alternate to ferro-columbium in the CF-8C type. The folder is titled "ACI Standard Designations and Chemical Composition Ranges for Heat and Corrosion Resistant Casting."

•

**Cathodic testing** equipment manufactured by J. L. Collins, P. O. Box 941, Angleton, Texas, is listed in a folder and price list available from the manufacturer.

•

**IPS Size** stainless steel "Zephyrweld" fittings, comprising its schedules 5 and 10 are described in Catalog 1051 available from Tri-Clover Machine Co., Kenosha, Wis. The new line augments the firm's line of tube OD butt weld, recessed end, flanged conical end types and sanitary type fittings.

•

**Dowell Incorporated** cleaning services for boilers, pipes, heat exchangers and other equipment is described in a booklet, "Cut Maintenance Costs with Dowell Service," available on request from the company, Dept. P, P. O. Box 536, Tulsa 3, Okla.

•

**"Brooks Chemical** and Technical Services," Bulletin 501, issued by Brooks Chemicals, Inc., 3304 East 87th St., Cleveland, Ohio, gives information on the firm's industrial water treatment and conditioning services.

•

**Properties and Uses** of Linde Synthetic Crystal Products are described in a 4-page booklet, "Linde Synthetic Crystals for Industry." Properties, available forms and uses for Linde synthetic sapphire, spindel, titania, calcium tungstate and fine alumina polishing powders, and illustrated uses where extreme hardness, low friction, high dielectric strength and resistance to wear, heat and corrosion are required are arranged in tabular form. Copies may be obtained from the firm, 30 East 42nd St., New York 17, N. Y.

•

**Alodizing** with "Alodine," a 4-page pamphlet, and "Amorphous Phosphate Coatings for Protection of Aluminum Alloys and for Paint Adhesion," by Alfred Douty and F. P. Spruance, Jr., a technical paper, have been issued by American Chemical Paint Company, Ambler, Pa.

•

**Corrosanti,** manufactured in four grades for different types of service, is described by the manufacturers as a boiler and metal protector. Grade A removes boiler scale and prevents further rusting when injected into feed water in small quantities. Grade B penetrates rust when applied with a stiff brush in air or under water, causing it to flake off. Subsequent rusting is inhibited. Grade C is designed to protect metal surfaces subjected to corrosives, including sea water. A special grade is designed for application to ferrous surfaces subject to temperatures up to 900 degrees F. Inquiries should be directed to 52 Cambridge St., East Orange, N. J.

•

**Polyethylene** containers from pint to 3-gallon size are made by a method developed by American Agile Corporation, Plastics Division, 5806 Hough Ave., Cleveland 3, Ohio, which includes a welded seam. Bottles, jugs and buckets are made with welded bottom, cover and spout. Further information and technical data can be secured.

•

**"Stop Corrosion With Tape,"** a 4-page folder showing the method of using Scotch Electrical Tape No. 22 in protecting gas service lines from corrosion underground, is available on request from Minnesota Mining & Mfg. Co., 900 Fauquier St., St. Paul 6, Minn.

**Hot Working** of ferrous alloys containing chromium, molybdenum, cobalt, copper, tungsten, silicon, manganese, columbium and vanadium now is possible through a patented development announced by Carpenter Steel Co. By the addition of cerium and/or lanthanum the company now is able to hot work sheets, rods and tubes of these corrosion resistant alloys. The material has been designated "Misch" metal. Cerium and lanthanum are by-products of the development of monazite sands, now being developed for their thorium content, a circumstance which makes them available in quantity. Investigation by Carpenter has shown nickel content to be the limiting factor in determining the quantities of cerium and lanthanum which must be added. The amount of the two elements which can be added to produce workability is inversely proportionate to nickel content. Corrosion and heat resistant grades included in the cerium-bearing range include AISI Stainless Types 309, 310, 316, 317, 320 and Carpenter Stainless 20 and Carpenter austenitic valve steels. Information about the new development and on licensing arrangements can be secured from the company's Reading, Pa., offices.

•

**Elsevier Press,** Incorporated, has located its main office in the United States at 402 Lovett Blvd., Houston 6, Texas.

•

**Vapor Degreasing Handbook,** a description of the uses of its equipment, has been printed by Phillips Manufacturing Co., 3475 W. Touhy Ave., Chicago, Ill.

•

**"Corrosion of Mild Steel** and Mild Steel Welds in Sulphate Digesters," Bulletin V-58, by R. A. Huseby and M. A. Scheil, of A. O. Smith Corp., Milwaukee, Wis., a paper presented at the New York City American Pulp and Paper Institute meeting February 21, 1951, is available in reprint form from the company. The paper gives results of tests under very corrosive conditions in a tumbling digester located in a paper plant on the West Coast. A principal finding was that a high oxygen content in the steel surface was very beneficial to high corrosion resistance.

•

**Patching of Mechanically** damaged rubber linings in corrosion service is possible with a new material, Carbo-Flex 6040, according to the Carboline Company, 7603 Forsythe Blvd., St. Louis 5, Mo. The material bonds perfectly to used, vulcanized rubber, shrinks about 1/10 of 1 percent, has corrosion resistance and heat resistance superior to rubber, readily mixed and hardens at room temperature in 2 to 3 days, or in several hours by using a catalyst or heat, is sufficiently flexible for most services but belt repairs, can be tested with a spark tester, obtains excellent bond to steel by use of a special primer, can be smoothed with denatured alcohol and has indefinite shelf

(Continued on Page 16)

THE NEW

# Polyken®

## INDUSTRIAL TAPES

TAILORED TO YOUR JOB

**Fifteen levels below ground** an air "life line" is sealed with new *Polyken* No. 822 polyethylene tape.

# A tape that helps men breathe ... a mile underground

This is the story of how a new kind of tape helps get air to men a mile down under Kellogg, Idaho, in the Bunker Hill Mine.

Fresh air is forced under pressure in 16" ducts through miles of underground tunnels. Naturally, duct joints must be tightly sealed or leaks develop and endanger lives. Tape is the fast, economical way to do this, but no tape could be found that would long resist the acids and fungus and the intense humidity of the underground without rotting or cracking.

Our engineers recommended *Polyken* No. 822. One of our 129 special tapes, No. 822 has a polyethylene backing (an elastic plastic). Not only does this tape conform to irregular surfaces, it keeps its high adhesion and tension indefinitely . . . even under conditions as unfavorable as those at the Bunker Hill Mine.

This is just one instance of how a tape that's "tailored to your job" can save you time and money —and in a case like this, maybe even a life! *Polyken* is the leader in this field, and we make this challenge: Let us study your particular problem. Nine out of ten times we'll come up with a tape that will do the job better, cheaper, and with less effort!

**GET THIS FREE BOOKLET!** To help you find the tape "tailored for your job," write for your free copy of "Tape is a Tool." Address *Polyken*, Dept. CG, 222 W. Adams Street, Chicago 6, Illinois, or see your *Polyken* distributor.

***Polyken* Industrial Tape, Department of Bauer & Black, Division of The Kendall Company**

## New Products—

(Continued From Page 14)

life. Tests kits with sufficient material to cover 60 sq. in. ⅛-inch thick and with a steel primer can be obtained.

•

**A Study** of 50 underground heat grid snow melting systems, with illustrations, is included in a 36-page booklet published by A. M. Byers Co., Pittsburgh, Pa. Copies may be obtained on request.

•

**More Pounds** of graphite per unit of exposed surface are provided by a new 3-inch by 60-inch National graphite ground anode. They are furnished with 36 inches of insulated No. 8 waterproof cable attached, or with special cables on order. Further details can be obtained from National Carbon Company, 30 East 42nd St., New York 17, N. Y.

•

**Alloy Steel Products** Co., Linden, N. J., has issued Technical Bulletin No. 5 illustrating and describing its Teflon-seated needle and plug gate valves. The valves incorporate molded renewable Teflon seats, outside stem threads and union bonnet construction.

•

**The Houston, Texas,** plant of Atlas Mineral Products Company is being expanded with the addition of a modern lining shop and storage facilities.

•

**Unichrome Dip** Compounds 1060 and 1070, which produce corrosion-resisting, chromate-type conversion coatings on zinc by a simple dipping process, have been developed by United Chromium, Inc., 100 East 42nd St., New York 17, N. Y.

•

**Taylor Forge** nozzles, welding necks, and flanges are described in Taylor Forge Catalog 501, which includes TEMA standards, the publication "Modern Flange Design," is thumb-indexed, and covered with a heavy cardboard cover. It is available to persons specifically interested in pressure vessel work on request written on company letterhead from Taylor Forge & Pipe Works, P. O. Box 485, Chicago 90, Ill.

### Notice to Authors of Technical Material in Corrosion

**For a handling charge of $5 the National Association of Corrosion Engineers will ship postage paid to authors of technical material published in CORROSION, not earlier than six months after publication, printing plates used for figures in articles, NACE undertakes to ship such printing plates as are available, without warranty as to their condition or completeness. Those who wish to take advantage of this offer are asked to submit a request in writing, giving the issue in which the article in question was published, full address to which plates are to be shipped and billing information to:**

**NORMAN E. HAMNER,**
**Managing Editor, CORROSION,**
**919 Milam Building,**
**Houston 2, Texas**

## PERSONALS

**Donald MacArthur** has been named assistant manager sales department, Koppers Company Central Staff.

•

**Ralph N. Hillner** has been named Central District Sales Manager by H. H. Harper Co., Morton Grove, Ill. He will supervise nine regional offices.

•

**Dr. Charles Allen Thomas** has been elected president of Monsanto Chemical Co. **William M. Rand,** retiring president, continues on Monsanto's board of directors.

•

**Thomas C. Beattie** has been appointed general superintendent of Fairless Works of National Tube Company. He will manage operations of new pipe mills being installed by National Tube near Morrisville, Pa.

•

**Raymond G. Ellis** will coordinate and direct sales promotion and advertising of Sel-Rex Precious Metals, Inc., Bart-Messing Corp., Bart Laboratories Co., Inc. and Bart Manufacturing Corp. He formerly was advertising manager of the Electrochemical Society's Journal.

•

**Harry E. Roche,** formerly manager of Koppers Co., Inc., chemical division, has been assigned to special duties in connection with construction of the division's new plant at Port Arthur, Texas; **A. A. Sellers** has become production manager of the chemical division and **Bernard R. Sarchet,** recently in charge of reactivation of the government-owned butadiene plant at Kobuta, has been named manager of the Koppers Kobuta plant, with responsibility for the adjacent government-owned plant.

•

**E. W. Pat Smith** has been elected vice-president of Owens-Corning Fiberglas Corp. He is in charge of merchandising and advertising programs, among others.

•

**H. P. Boncher,** general manager of Dresser Manufacturing Division, Bradford, Pa., has been elected vice-president of Dresser Industries.

•

**Fred S. Haggerston,** president of Union Carbide and Carbon Corp., has been elected chairman of the board of directors.

•

**Nelson Evans Cook,** general superintendent of galvanizing for Wheeling Steel Corp., received the Galvanizers Committee's annual award at St. Louis May 21 during the annual convention of the committee.

•

**Dr. Jess Harrison Davis** has been elected to succeed Dr. Harvey Nathaniel Davis 70, as president of Stevens Institute of Technology, Hoboken, N. J., effective September 1, 1951. They are not related.

•

**R. A. Gloss** has been appointed sales representative for Federated Metals Division, American Smelting and Refining Co., of the Wisconsin and upper peninsula territory.

•

**Thomas R. Lawson** has been named assistant salesmanager of industrial products of Westinghouse Electric Corp.

### HALF-YEAR MEMBERSHIPS

**NACE by-laws provide that those applying for Active (individual) Membership in the association subsequent to June 30 shall pay dues of $5 for the remainder of the calendar year.**

- **The half-year membership includes issues of CORROSION magazine, July-December inclusive.**

**George E. Shaw,** associated with Petro-Chemical Equipment Co., Houston, has returned recently from Iran where he was consulting engineer on installation of a group of filters in the Adaban Refinery of Anglo-Iranian Oil Co. He was in Iran when rioting broke out over nationalization of the oil industry.

•

**Herb Walther, Jr.,** has been placed in charge of sales of cathodic protection products for Dowell, Inc.

•

**Lachlan W. MacLean** has been appointed to the post of vice-president in charge of manufacturing and engineering by Dampney Co., Boston, Mass.

•

**Bert C. Prisk** has joined with the corrosion engineering staff of Hinchman Corp., Detroit, Mich.

## Instrumentation Film

A 55-minute, 16-mm, full color sound motion picture "Principles of Automatic Control," produced by the Instrument Society of America, 921 Ridge Ave., Pittsburgh 12, Pa. may be obtained for showing by ISA sections and educational institutions without charge. Other societies will be charged $5 per showing and business firms $10 per showing, to cover packing, shipping, inspection and maintenance costs.

•

News about the activities of organizations anywhere in the world engaged in corrosion mitigation are welcomed for use in the news section of CORROSION.

•

Corrosion mitigation processes and materials are publicized free of charge in CORROSION's "New Products" section. NACE accepts no responsibility for accuracy of performance claims.

### FREE *Reprints* While Supply Lasts

***The Influence of Stress on Corrosion,*** **by Julius J. Harwood, Office of Naval Research, Washington, D. C. Reprinted from CORROSION, Vol. 6, No. 8 and and 9 (1950). A paper presented at the NACE meeting, St. Louis, Mo., April, 1950.**

**Address your request to: Norman E. Hamner, Managing Editor, Corrosion, 919 Milam Bldg., Houston 2, Texas.**

# Corrosion Abstracts

CORROSION CONTROL — PROTECTIVE INDUSTRIES — NATIONAL ASSOCIATION OF CORROSION ENGINEERS — ORGANIZED 1943 — INCORPORATED


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Vol. 7 July, 1951 No. 7



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(Complete Topical Index used for Corrosion Abstracts may be found in FIVE YEAR INDEX TO TECHNICAL ARTICLES, Corrosion, December, 1950.)

*** PAGINATION OF CORROSION ABSTRACTS**

Two numbers appear on each page of Corrosion Abstracts. The number in the upper outer corner is for page sequence within the issue only. The number in the lower outer corner, which is followed by the letter "a," denoting "abstracts," is for the convenience of those who bind Corrosion Abstracts by volumes. Because both numbers appear on each page and because it is believed indexing by the volume serial number will be more useful, the "Index to Corrosion Abstracts" is keyed to the number in the lower outer corner of each page followed by the letter "a."

## GENERAL

### • Fundamentals

1.8, 3.6

**The Reaction Mechanism of the Oxygen Cell in Relation to the Local Element Theory of Corrosion.** G. Brinkmann. *Werkstoff u. Korrosion,* **I,** 217-232, (1950), June-July.

Description of new theory as applied to combinations of active carbon-zinc, active carbon-iron and active carbon-aluminum. Electrolytes include ammonium chloride, copper sulphate, potassium sulphate, and sodium chloride. Method evolved is adapted for examination of various matters affecting use of metals, electrolytes and depolarized anodes in galvanic elements and in connection with reactive behavior of active carbon.

## TESTING

### • General

2.1, 1.7, 5.4

**Breakdown of Paint Films on Steel Surfaces: Standard Degrees of Rusting.** British Iron and Steel Research Association. Leaflet, Dec., 1949, 3 pp.

Five natural size photographs depicting different grades of breakdown by rusting of painted steel surfaces exposed in the tests of Joint Technical Panel J/P1 (Paints for Structural Steelwork) of the Protective Coatings Sub-Committee, BISRA.

### • On Location Tests

2.2, 2.3, 5.3, 4.2, 1.7

**Report of Committee A-5 on Corrosion of Iron and Steel.** ASTM Preprint 3, (1950) 29 pages.

Includes miscellaneous committee recommendations; subcommittee reports on total immersion tests, on atmospheric exposure of black and galvanized sheets, wire and wire products and bare and metallic coated hardware structural shapes, plates, bars, etc. Data are tabulated. Also includes proposed revised tentative specifications for zinc-coated iron or steel sheets, coils, and cut lengths; also long terne iron or steel sheets, coils, and cut lengths.—BLR.

2.2, 1.7, 6.3, 6.4

**Report of Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys.** ASTM Preprint No. 9, (1950) presented at the 53rd Annual Meeting of the Society, (1950) June 26-30.

At the meeting of the committee on February 27, 1950 in Pittsburgh, Pa., Subcommittee VI on atmospheric corrosion reported that all test specimens had been removed from the La Jolla, Cal., test site because the area was required by the Oceanographic Institute. The plate specimens will be cleaned and weighed and the tensile specimens pulled. Specimens of light metals will be placed on exposure this summer by the subcommittee and committee B-7. Results of exposure of zinc and steel specimens for one year were reported by Subcommittee VII on weather. Sub-

**PRIMARY SOURCES OF ABSTRACTS PUBLISHED IN CORROSION**

AER—Aeronautical Engineering Review, Institute of Aeronautical Sciences, Inc. 2 East 64th St., New York 21, N. Y.

ALL—The Abstract Bulletin, Aluminum Laboratories, Ltd. P. O. Box 84, Kingston, Onatrio, Canada.

AWWA—Journal, American Water Works Association. Amer. Water Works Assoc., 500 5th Ave., New York 18, N. Y.

BL—Current Technical Literature, Bell Telephone Laboratories, Inc., Murray Hill, N. J.

BLR—Battelle Library Review, Battelle Memorial Institute Library. 505 King Ave., Columbus, Ohio.

BNF—Bulletin; British Non-Ferrous Metals Research Association. 81-91 Euston St., London NW 1, England.

CALCO—Calco Chemical Division, American Cyanamid Corp. Bound Brook, New Jersey.

CE—Chemical Engineering, McGraw Hill Publishing Co. 330 W. 42nd St., New York 18, N. Y.

CEC—Consolidated Edison Co. of New York, Inc. 4 Irving Place, New York 3, New York.

EW—Electrical World, McGraw-Hill Publishing Co. 330 W. 42nd St., New York 18, N. Y.

GPC—General Petroleum Corp. of California. 2525 East 37th St., Los Angeles 11, Calif.

INCO—The International Nickel Co., Inc. 67 Wall Street, New York 5, New York.

IP—Institute of Petroleum. 26 Portland Place, London W#1, England.

MA—Metallurgical Abstracts, Institute of Metals, London, England. 4 Grosvenor Gardens, London SW 1, England.

MI—Metallurgia Italiana. Associazone Italiana di Metallurgia. Via S. Paola, 10, Milano, Italia.

MR—Metals Review, American Society of Metals. 7301 Euclid Ave., Cleveland 3, Ohio.

NALCO—National Aluminate Corp. 6216 West 66th Place, Chicago 38, Illinois.

NBS—National Bureau of Standards. Supt. of Documents, U. S. Gov't Printing Office, Washington 25, D. C.

PDA—Prevention Deterioration Abstracts. National Research Council, 2101 Constitution Ave., Washington 25, D. C.

RA—Refrigeration Abstracts, American Society of Refrigeration Engineers. 40 West 40th St., New York 18, N. Y.

RM—Revue de Metallurgie, Paris, France. 5 Cite Pigalle, Paris (9e), France.

RPI—Review of Current Literature Relating to the Paint, Colour, Varnish and Allied Industries, Research Association of British Paint, Colour & Varnish Manufacturers, London. Waldegrave Rd., Teddington, Middlesex.

TDD—Technical Data Digest, Air Material Command—Technical Service Section, Central Air Documents Office, Wright-Patterson Air Force Base, Dayton, Ohio.

TIME—Transactions of Institute of Marine Engineers. 85 The Minories, London EC 3, England.

UOP—Universal Oil Products. 310 South Michigan Ave., Chicago, Illinois.

ZDA—Zinc Development Association. Lincoln House, Turl Street, Oxford, England.

committee VIII on galvanic and electrolytic corrosion reported that the work of placing disk-type specimens of two types of magnesium alloys coupled galvanically to other metals and alloys has been completed and that spool-type specimens will be exposed before the end of the year when the preparation of the plate-type specimens will be undertaken.—ALL.

2.2, 4.2, 1.7, 6.5

**Mechanical Property Data on Magnesium-Base and Zinc-Base Die-Cast Alloy Specimens After 10-Year Atmospheric Exposure.** Report of ASTM Committee B6 on Die Casting Metals and Alloys. ASTM Preprint 12 (1950) pp. 3-6.

Gives the results of exposure at five outdoor and three indoor sites after ten years. Results include tensile strength, impact, elongation, Rockwell harness and dimensional change.—BNF.

## • Laboratory Methods & Tests

2.3, 1.8

**Two Radioactive Methods for Studying Certain Gas-Metal Reactions.** Clifford K. Beck, University of North Carolina, State College of Agriculture and Engineering. *Science, 110,* 371-372 (1949) Oct.

The rate, acceleration, and extent of gas-metal reactions, as well as certain properties of the deposited films, may be studied by either of two radioactive techniques provided a solid, adherent reaction product results and the radioactive component of the gas phase becomes a component of this solid product.

Either experimental system is easily set up and gives reliable results quickly. The reaction need not be stopped to permit periodic observations of the extent of reaction as it must in the cumbersome weight-gain method. With proper calibration either method gives absolute values of corrosion rates; relative rates between different metals and a given gas are even easier to obtain. For reproducible data, extreme care is rquired in preparing smooth, clean, uniform surfaces.

In the first method, the metal to be studied is made into a counting tube, e.g., 1 in. in diameter and 10 in. long. From the insulated end of this tube a fine wire, perhaps 0.003 in. in diameter, of the same or of an inert metal is suspended along the tube axis as a high-voltage ion-collecting electrode. After the background counting rate is determined, the radioactive, corrosive gas is introduced for a predetermined period of time, say 1 min.

In the second method the metal is made into a fine wire, about 0.005 in. in diameter, which is wound into a loose coil and exposed continuously to the radioactive, corrosive gas in a suitable chamber. Measuring the activity of consecutively withdrawn samples at regularly increased periods of exposure gives a systematic history of the reaction.—PDA.

2.3, 5.4

**Color Photography as a Technical Aid in the Scientific Study of Paint Products.** Golden Gate Paint & Varnish Production Club. *Am. Paint J., Conv. Daily,* **34,** No. 6E, 30 (1949); also in *Off. Dig.,* No. 298, 806-7 (1949).

The advantage of color photographic records of paint films subjected to durability tests is described.—RPI.

2.3, 5.4, 4.6

**Spray Testing with Natural and Synthetic Sea-Water. II. A Study of Organic Coatings.** Allen L. Alexander and Thomas P. May. ASTM Preprint, 1950 (No. 26) 6 pp.

Eight different paint systems were applied to mild steel and a ninth to magnesium and to anodized 24S-T aluminum alloy. Specimens were exposed to a salt fog test using the following corroding agents: natural sea-water, synthetic sea-water, and 3 and 20% sodium chloride solutions. The results of total immersion in sea-water and of exposure to marine atmospheres are given for comparison. The results with synthetic sea-water spray were closely parallel to those with natural sea-water, though for long-term experiments the natural was slightly more corrosive than the synthetic sea-water. For organic coatings on steel 3% sodium chloride solution had the most severe effects and 20% solution caused slightly less corrosion, but still more than the sea-waters. Close agreement between replicate specimens was found, and the differences between individual spray cabinets remained relatively constant throughout.—MA.

2.3, 5.3

**The Use of Multiple-Beam Interferometry for the Determination of the Thickness of Thin Metallic Coatings.** D. G. Avery, *Brit. Sci. News,* **3,** No. 27, 81-84 (1950).

The use of multiple-beam interfer-

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ometry for measuring the thicknesses of thin metallic films produced on optically flat glass by evaporation or sputtering processes is described. Apparent thicknesses of the order of 50 A can be measured to within ± 10%; with apparent thicknesses above 150 A the error is ± 5% or less.—MA.

## • Instrumentation

2.4

**Brazed Tool-Tips:** Non-Destructive Testing Method Developed by the Bristol Aeroplane Co., Ltd., *Aircraft Prod.*, 11, No. 31, 295-297 (1949).

A non-destructive, electrical method for testing the brazed joints of carbide-tipped high-speed steel cutters is described. A brief description of the normal routine brazing of the tips is also included.—MA.

2.4

**Flaw Detector for Metals.** *Aero Digest*, 19, (1950) July.

A new inspection process called "Dy-Chek" makes possible, more quickly and easily, the detection of flaws in metal surfaces. An ordinary mechanic may carry out inspection. A cleaner, a red dye and a white developer are applied successively to surfaces to be tested. The microscopic flaws show up clearly. Parts may be inspected without removal from assembly, provided they can be seen. Testing materials are nontoxic and noncorrosive.—TDD.

2.4, 8.4

**Nondestructive Testing of Drill Pipe.** Norman Bowers. *World Oil*, **131**, 87-90-92 (1950) July 1.

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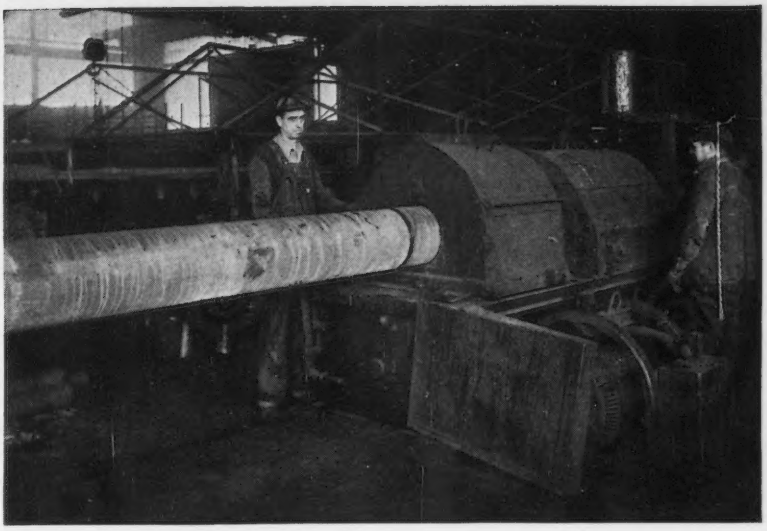

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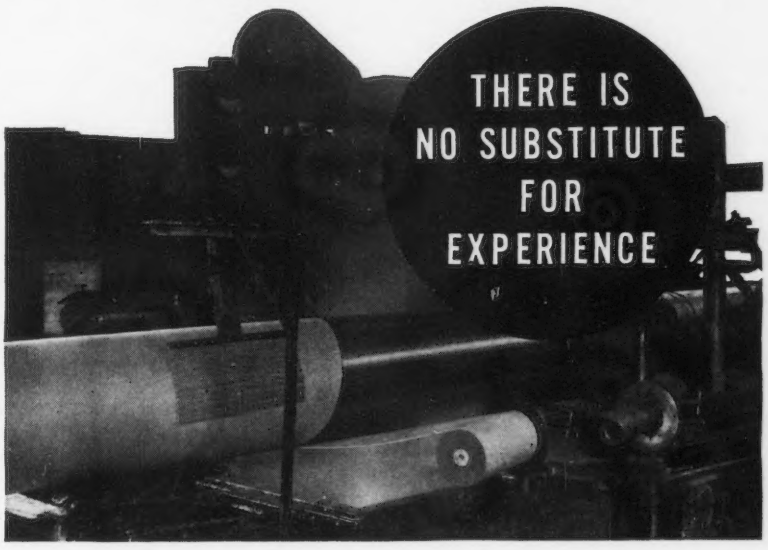


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out limitations of those that might be used for the inspection of new and used drill pipe.—BLR.

2.4, 5.3

**An X-Ray Method for Determining Tin-Coating Thickness on Steel.** H. F. Beeghly, *J. Electrochem. Soc.*, **97**, No. 4, 152-157 (1950).

A simple X-ray technique is described which enables the thickness of tin coatings on steel to be measured rapidly and non-destructively on either side of the sheet. The method is based on the selection of an X-ray beam of a wavelength that excites significant amounts of secondary radiation in the base metal but not in the coating. The results obtained by this method are comparable in accuracy and reproducibility with those obtained by the usual chemical methods. Full details of the technique employed are included and although the data have been obtained during a laboratory investigation, sufficient work has been done to show that the principle used for measuring tin coatings on steel is applicable to other metals and also that it can be used for the continuous indication and control of tin-coating weights in continuous tinning plants. An apparatus for the latter purpose has been designed and built.—MA.

## • Standardization & Specifications

2.5

**pH Scale, British Standards Institution.** British Standard 1647; 12 pp. (1950). Published by the Institution, 24/28 Victoria Street, London, S.W.I. 2s.—BNF.

2.5, 2.2, 1.7

**Tentative Method of Salt Spray (Fog) Testing.** ASTM Standards, Pt. 2, 786-93 (1949).

B 117 has been revised. Appendices give details of suitable apparatus and a note on the use of the test in research, serving to point out its limitations.—RPI.

2.5, 4.6, 1.7

**Standard ASTM Method of Corrosivity Test of Industrial Water.** U. S. Bur. Mines Embrittlement Detector Method. (D807-49)—ASTM Standards on Industrial Water, 1462-1468 (1949).

Standard ASTM method of corrosivity test of industrial water. Nat. District Heating Assoc. Method. (D935-49)—(ibid., 1515-1518).—MA.

2.5, 4.6, 1.7

**Report of Committee D-19 on Industrial Water.** ASTM Preprint No. 98, 50 pp (1950).

Gives committee report and 9 tentative standards. These include "Identification of Types of Microorganisms in Industrial Water" (pp 24-28); "Proposed Revision of Tentative Method of Test for Total Carbon Dioxide and Calculation of the Carbonate and Bicarbonate Ions in Industrial Water (D513-48T)" (pp 29-30), and "Identification of Crystalline Compounds in Water-Formed Deposits by X-Ray Diffraction" (pp 39-43). See also "ASTM Standards on Industrial Water," Dec., (1949), 134 pp. $1.75.—BNF.

# CORROSION TYPES & INFLUENCING FACTORS

## • Types

3.2. 5.4, 2.3

**Report on Marine Growth Investigations Carried Out During Recent Years.** Admiralty Dept. of Research Programmes & Planning. ACSIL Translation No. 414, (PG41646) ACSIL/ADM/49/235. *J. Brit. Shipbuilding, R. A.*, **4**, No. 11, 512 (1949).

The first part of the report covers investigations of marine growth, amount of poison liberated from a painted surface by the action of sea water and the solubility of the purely toxic components in sea water. A further chapter deals with the poison storage by marine growths. A brief survey of the biological research work and rapid testing methods is given. The second part of the report deals with the influence of metals on marine growth, and the toxic action of organic and inorganic heavy-metal combinations in paints.—RPI.

3.2, 6.3, 4.6, 3.7

**Types of Corrosion of Brass Tubes by Contaminated River Water and Their Prevention.** (In German.) J. Bunger. *Werkstoffe u. Korrosion*, **1**, No. 4, 133-136 (1950) Apr.

Experiences with condenser and cooler tubes with condensate containing ammonia and oxygen, and in polluted Saale water with a high chloride content, suggest that stress corrosion and dezincification are best avoided with 70/30 brass, with or without 1 percent tin, with a recrystallized but not too coarse structure obtained by annealing at 625° C, cold-working 12 percent, and stress-relieving at 450-500° C.—BNF.

## • Factors Biological

3.3, 6.6, 2.3

**Microbiological Deterioration of Cellulose During the First 72 Hours of Attack.** Edward Abrams. *Textile Res. J.* **20**, 71-86 (1950) Feb.

Loss of tensile strength of cotton duck during the first 72 hours of incubation was determined using 5 cellulolytic organisms. Study of mildewed fibers in dilute alkali showed localized nature of attack and production of alkali-soluble material. Latter was studied by infrared absorption. Includes tables, graphs and micrographs. 31 ref.—BLR.

3.3, 5.4, 2.3

**Anti-Fouling Compositions; Accuracy of Leaching Rate Determinations.** H. Barnes. *J. Soc. Chem. Ind.*, **68**, No. 10, 305-8 (1949).

A statistical evaluation of variability of results, employing copper oxide and phenarsazine chloride toxins in standard compositions. From the coefficients of variation of leaching rate it is concluded that errors arise in the analysis of the rate of copper oxide leaching from the presence of fouling and that the increased variability of the results with phenarsazine chloride arises from the complex analytical technique. It is concluded that standardization of formulation, application and exposure conditions is more important than refinement of analytical technique.—RPI.

3.3, 6.4, 5.4

**Anti-Fouling Compositions for Aluminum Alloys.** Admiralty Corrosion Committee. Hull & Non-ferrous Corrosion Sub-Committees, ACSIL/ADM/49/32. *J. Brit. Shipbuilding, R. A.*, **5**, No. 3, 170, (1950).

Results are given of investigations of proprietary anti-fouling compositions on aluminum alloys. The best of the compositions failed after 13 weeks' exposure and a few of them caused excessive corrosion when applied directly to the aluminum. The whole problem of anti-fouling compositions for aluminum alloys required extensive investigation.—RPI.

## • Factors Physical and Mechanical

3.5, 7.1

**Stop Accelerated Oxidation and Get Better Jet Engines.** Anton De S. Brasunas and N. J. Grant *Iron Age*, **166**, 85-90, (1950), Aug. 17.

Formation of oxides of vanadium, bismuth, wolfram and lead on high-temperature steel is shown to promote "accelerated oxidation," because of contamination of the original oxide phase. The corrosion product formed does not act as a barrier to continued attack. The scale layer is either entirely unprotective, leading to a linear rate of oxidation, or it causes more intense attack to occur as the scale layer thickens, resulting in a continually accelerating rate of oxidation. Test samples are illustrated following high-temperature air oxidation. Data are tabulated showing optimum compositions for minimizing attack. Effects of external contaminations were studied. 15 references.—BLR.

3.5, 6.2

**Researches on the Oxidation of Iron-Nickel Alloys at Elevated Temperatures.** J. Benard and J. Moreau. Report of IRSID research. *Rev. Metallurgie*, 47, 317-323 (1950) Apr.

Alloys containing 5, 10, 20 and 30 percent nickel, balance iron were exposed as strips 0.5 or 1 mm thick. Samples oxidized in air at temperatures up to 950° C, for varying periods. Report on general appearance of the oxidized specimens, surface and internal oxidation effects and kinetics of the oxidation occurring was made.—INCO.

3.5, 4.3, 3.7

**Caustic Danger Zone.** A. A. Berk and W. F. Waldeck. *Chem. Eng.*, **57**, 235-236, 238 (1950), June.

Cracking of tanks, evaporators, and heat exchangers in which stressed steel is exposed to solutions containing concentrated sodium hydroxide is discussed. It was found that the region in which cracks occur is greatly extended, and the probability of cracking within the region is greatly increased, through the additions to the solution of small amounts of lead oxide or of oxidizing materials as nitrates and permanganates. Manufacturers of caustic soda have no such trouble since they have converted to nickel equipment. In handling hot, concentrated solutions cracks developed in highly stressed parts, as rivet heads,

riveted seams and welds. Avoidance of these areas reduces the probability of cracking. Temperatures and concentrations where caustic soda is liable to crack stressed steel are given in chart form. Best results are obtained by keeping below 180° F and between 15-43 percent concentrations.—INCO.

### • Factors Electrochemical

3.6, 1.8

**The Role of Polarization in Electrochemical Corrosion.** R. H. Brown, G. C. English and R. D. Williams. Paper before NACE, Ann. Mtg., St. Louis, (1950) April 4-7. CORROSION, **6**, No. 6, 186-195 (1950) June.

In its practical aspects as well as in its fundamental mechanisms, electrochemical corrosion is almost always associated with irreversible electrode phenomena. The multitude of factors involved in these phenomena may be defined as electrochemical polarization. Methods of correlating polarization with corrosion data such as weight loss are shown. A method for obtaining the contribution made by the polarization of each electrode reaction to the total polarization observed at an electrode is described along with the implications thereof in the evaluation of the true over-voltage values. Other factors which fall within a broad definition of polarization are treated. 13 references.—INCO.

3.6, 7.5

**Peculiar Case of Corrosion.** H. Bourquin. *Schweiz, Bauztg.*, **67**, 735 (1949); *J. Brit. Shipbuilding R. A.*, **5**, No. 2, 100 (1950).

An instance is quoted of the holeing of an oil tank made of 3/16-inch mild steel plate coated with bituminous paint. A copper pipe ended about ⅛-inch above the hole and was in metallic connection with the water supply system. The hole was caused by the electrolytic corrosion due to a difference in potential between the piping of the water system and the walls of the tank. The oil and water mixture in the bottom of the tank acted as electrolyte.—RPI.

3.6, 6.4

**Galvanic Contact Corrosion.** Metals in Contact with Aluminum and its Alloys. Aluminum Ltd. *Aluminum News*, **3**, No. 4, 1 (1950) Apr.

Brief practical notes on galvanic action between aluminum or its alloys and other metals, with necessary preventive actions.—BNF.

## CORROSIVE ENVIRONMENTS

### • General

4.1, 5.4

**Perspiration and Paint Discoloration.** R. J. Bithell. *Paint Tech.*, **15**, 169, 11 (1950).

Pale green paint based on a urea/alkyd mixture discolors on handling. Pigments affected are Brunswick green, chromic oxide and phthalocyanine. Cellulose enamels are unaffected. The activity of perspiration varies with different people and with the same person at dif-

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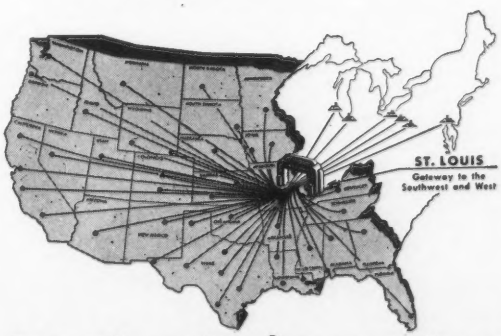


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ferent times. Formulae for synthetic perspiration are given. No conclusive decisions have been reached regarding the effect of perspiration on paint films. —RPI.

## • Chemicals Inorganic

4.3, 6.3

**And Now Titanium Tubing.** A. M. Bounds. *Iron Age,* **165,** No. 14, 85-89 (1950).

By means of inert-atmosphere welding and annealing titanium is now available as tubing. For this purpose the metal should be at least 99.5 percent pure. It has excellent corrosion-resistance to aqua regia, boiling acetic acid, nitric acid, boiling calcium chloride, wet chromic gas and sea water, but to hydrochloric only if dilute. It has poor resistance to sulfuric acid, and none to hydrofluoric acid. Describes the mechanical properties of this tubing and gives the metallographic technique for examining specimens of titanium.—MA.

4.3, 5.8

**Additives for Lubricating Oils.** E. R. Booser, Gen. Elec. Co. *Gen. Elec. Rev.,* **53,** No. 8, 9-13, (1950), Aug.

The addition of chemical additives to lubricating oils changes certain properties which make them rather limited in utility. Oxidation inhibitors, rust inhibitors, lubricity agents, viscosity index improvers and pourpoint depressants and defoaming agents are discussed. Oxidation curve and curve showing the reduction in friction are given. 17 references.—INCO.

## • Chemicals Organic

4.4

**The Importance of Surface Oxide Films in the Friction and Lubrication of Metals. Part I. The Dry Friction of Surfaces Freshly Exposed to Air. Part II. The Formation of Lubricating Films on Metal Surfaces.** E. D. Tingle. Trans. Faraday Soc.,**46,** 93-102 (1950) Feb.

A new "cutting" technique of surface preparation is used to demonstrate effect of the surface oxide film on friction and lubrication of metals. With unlubricated surfaces, the oxide film generally produces a marked reduction in friction even though the period of exposure to the atmosphere of a freshly cut surface is only a few seconds. With subsequent growth of the film there is further reduction but the effect is less marked. Experiments with lubricated surfaces emphasize the importance of chemical attack on boundary lubrication by fatty acids and demonstrate the essential part played by the oxide film in formation of the lubricating layer. The combined action of water and atmospheric oxygen on the surface of a reactive metal is often able to produce a film which will react with a fatty acid to give an effective lubricating layer. On the basis of the results, lubricating properties of long-chain fatty acids on three main classes of metals are explained. 22 ref.—BLR.

4.4, 7.1

**The Mechanism of Lubricating Oil Breakdown and Its Relation to Oil Corrosion.** W. F. Weiland. *Scientific Monthly,* **71,** 121-122 (1950) Aug.

Speculates concerning the mechanism of the above breakdown and of the accompanying corrosion. Discusses four methods which have been used in the author's laboratory to correlate acid-vapor temperatures with incipient corrosion. (Acid-vapor temperatures are those at which volatile acids first form.)—BLR.

4.4, 2.1

**Relationship of Metal Weight Loss to Absorption.** (In German.) K. Wickert and J. Kroll. *Werkstoffe und Korrosion,* **1,** 105 (1950) Mar.

Refers to weight-loss due to absorption. Experiments on carbon dioxide absorption by ferric hydroxide show that such absorption greatly affects the rate of corrosion of iron and steel. Tests were made with uncoated sheet iron and with sheet iron coated with "A-carbon" and with ferric hydroxide suspended in carbon dioxide and oxygen-containing water.—BLR.

4.4

**Sulfur Compounds from Petroleum Hydrocarbons—Reaction and Derivatives of Tertiary Aliphatic Mercaptans.** W. A. Schulze, G. H. Short and W. W. Crouch, Phillips Petro. Co. *Ind. Eng. Chem.,* **42,** No. 5, 916-921 (1950) May.

The di-tert-butyl disulfides are used as an ingredient in high pressure gear lubricants. They have a purity of 90 percent with a minimum sulfur content of 35.0 percent in SAE motor oil. They are not corrosive to polished copper at temperatures below 220° F. The corrosive activity of tertiary aliphatic sulfur compounds and engine tests on sulfenamides as lubricating oil additives are given in chart form. 21 References.—INCO.

4.4, 6.5

**Action of Organic Acids on Metals.** V. D. Yakhontov. *J. Applied Chem., U.S.S.R.,* **19,** 761-772 (1946). *Brit. Abs.,* BI, **1949,** 252-253 Apr. *J. Iron & Steel Inst.,* **165,** Part 1, 124 (1950) May.

The corrosion of steel (0.15 carbon, 0.01 copper, 0.25 manganese, 0.05 sulfur), aluminum, lead, copper and tin by various organic acids was studied. The action of acids of the same class decreases as the dissociation contant falls and as chain length increases but no strict proportionality occurs. No relation between the dissociation constant, structure and corrosion was found for hydroxyacids. Relations were determined between the rate of corrosion and concentration and temperature. The corrosion rate is highest in the first few seconds of the action, and becomes constant after 20-40 hr.—MA.

## • Soil

4.5

**Failures of Rubber Insulation Caused by Soil Microorganisms.** J. T. Blake, D. E. Kitchin and O. S. Pratt. *Elec. Eng.,* **69,** No. 9, 782-787 (1950) Sept.

The failure of rubber insulation caused by soil microorganisms can best be detected by a decrease of several decades in the insulation resistance. To study the mechanism of attack and the physical structure that makes rubber insulation vulnerable to such attack, it is necessary to locate and mark the failed spots. Several methods of doing this are described. The electrodeposition of copper in the micropores created by microbes affords the most insight into physical structure of the faults. Two distinct modes of attack are shown. The simpler one, characteristic of natural rubber, is a progressive eating away of the bulk insulation. The second, more obscure type, creates micropores through the wall, without visible surface erosion. This mode is typical of synthetics in which the base hydrocarbon or polymer does not support microbe growth. The imperfections consist of minute streaks of microbe food scattered in a random manner through otherwise inert material.—TDD.

4.5, 1.7, 2.4

**Report of Corrosion Committee.** Sidney E. Trouard. *AGA. Proc.* **31,** 487-496 (1949). (TP 700 Am 35 p.)

Includes reports of subcommittees on causes of underground corrosion of metals, underground corrosion mitigation practices, instrumentation and above-ground corrosion-mitigation practice. Also includes paper entitled "Your Corrosion Problems Can't Be Solved on a Hit or Miss Basis," Pat H. Miller—BLR.

## • Water and Steam

4.6, 6.6, 3.3

**Deterioration in Cooling Towers.** D. R. Baker, The Marley Company, Inc., *Sou. Power & Ind.,* **68,** No. 6, 64, (1950) June.

Two types of wood deterioration, chemical and biological are discussed. Delignification is a type of chemical attack generally attributed to sodium carbonate in the circulating water. Other facts that influence delignification include iron, chlorine, aeration and sulfur compounds.

Biological deterioration has been observed in two types of decay. Brown cubical rot and light pocket rot are attributed to wood-destroying fungi. Work is being done in isolating all of the known types of fungi involved.

This article is a progress report abstracted from "Wood Deterioration in Cooling Towers," presented at the April ASME Region VIII meeting in Dallas, Texas.—NALCO.

4.6, 4.3

**Neutralization of Spent Caustic With Flue Gas.** K. M. Brown, Universal Oil Products Co. & S. Kurtis, Aurora Gasoline Co. Paper before Western Petroleum Refiners Assn., Regional Mtg. *Oil & Gas J.,* **49,** No. 11, 81+ (1950), July 20.

Discussion on the various means available for neutralizing spent caustic to a tolerable pH includes, chemical oxygen demand of some sulfur compounds, types of waste caustic, and disposal of spent caustic.—INCO.

4.6

**New Results on the Electrical Treatment of Water.** Bruninghaus. *Arch. Metallkunde,* **3,** No. 12, 429 (1949. Cf. G. Seelmeyer. *ibid.,* **1,** 475 (1947); *Met. Abs.,* **16,** 714, (1948-49).

Ultra-short, electromagnetic waves having frequencies of $3 \times 10^6$ to $3 \times 10^9$ kHz. are shown to be particularly effective for softening water.—MA.

4.6, 8.4

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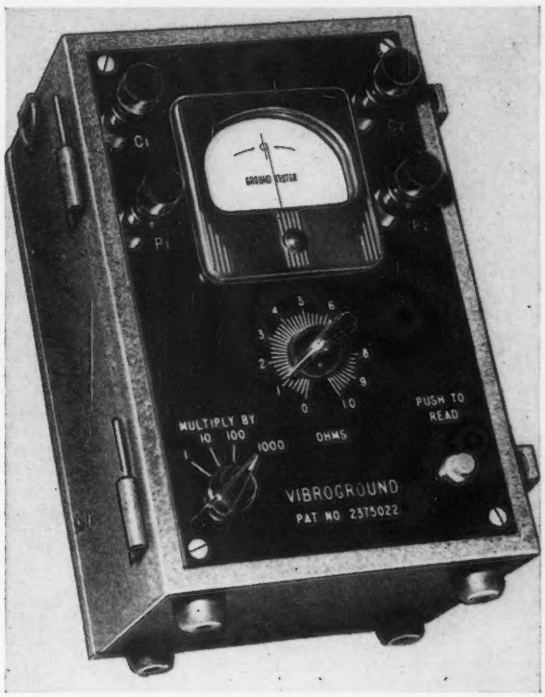


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**Scale and Corrosion.** J. C. Albright. *Petro. Ref.*, **29**, No. 7, 119-122 (1950) July.

A water treating system at the Barnsdall Oil Co. absorption and compression plant at Newhall, Cal., provides water free from scale and corrosion. The water is first treated with alum, sand filtered and then treated with Zeolite water softener. Sulfuric acid stored in a plastic tube keeps the pH of the water at 7.5-8.0. The cooling towers are kept as dark as possible to control algae growth and bromine is introduced to keep down this growth. The process is so efficient that no cleaning of exchangers, coolers, etc., has been necessary for the 20 months that the plant has been in operation. Flowsheet. Photographs.—INCO.

**4.6, 3.5, 6.2, 2.3**

**Behavior of Materials in Contact With Steam at Temperatures up to 600° C.** (In German) G. Bandel and H. J. Wiester. *Brennstoff-Warme-Kraft*, **1**, 203-208 (1949) Nov.

Results of this study indicate that although increased steam pressure and temperature reduce the relative fuel consumption of power plants, they also reduce life of the steam turbine. Tests were made to determine the high-temperature properties of highly alloyed austenitic steels. Results are graphed and tabulated. 16 ref.—BLR.

**4.6, 6.6, 3.3**

**Chemical Deterioration of Cooling-Tower Lumber.** C. L. Blohm and H. D. Frazier. *Oil Gas J.*, **48**, 72-75 (1950) Mar. 16.

The employment of cooling towers in the process industries for the dissipation of mass heat loads has been of general practice for many years and this practice has been quite satisfactory from the standpoints of operation and economic considerations. However, such towers, when constructed of wood, are subject to certain types of deterioration, among which are chemical and bacterial attack, attack by other living organisms, such as the teredo and similar wood-chewing insects and fouling of the structure by algal growths. This paper discusses chemical deterioration as involved in the failure known as "delignification." From their studies, the authors conclude that while certain means may be taken to prevent delignification of parts of the tower structure, protection of the operating sections can be attained only by suitable control of the circulating water.—GPC.

**4.6, 8.9**

**Corrosion and Related Problems in Sea-Water Cooling and Pipe Systems in H. M. Ships.** I. G. Slater, L. Kenworthy and R. May. *J. Inst. Metals*, **77**, No. 4, 309-330 (1950).

A study is presented of corrosion and related problems that were encountered in sea-water cooling systems during wartime service. Details are given of the deterioration liable to occur in the component parts of the system, such as inlets, valves, gratings, pumps, trunking, condenser doors, tube-plates, ferrules, condenser tubes, and piping. Impingement attack and deposit attack were the two most prominent types of corrosion encountered. It is shown that the main factors which influence these are water speeds with related eddies and turbulence, entangled air bubbles, tube obstructions and contamination of the water. Remedial and palliative measures are discussed in relation to the corrosion-resistance of the materials and protective coatings available; the use of different alloys in the same system; modifications of design for minimizing the severity of the conditions and the importance of maintenance routines. Laboratory tests and especially the jet-impingement apparatus are shown to be of great value in indicating the probable service behavior of materials, provided certain precautions are observed.—MA.

**4.6**

**Considerations on the Softening of Water with Barium Salts.** L. von Stanisavlievici. *Schweizer Archiv.*, **16**, No. 1, 21-25 (1950) Jan.

Author concludes that only barium hydroxide and barium aluminate ($BaAl_2O_4$) are suitable for softening water, the latter via hydrolysis into the hydroxide. Only waters free or almost free from magnesium ions, or those containing solely magnesium ions, can be treated. Waters must be free from chlorides.—BNF.

**4.6. 7.6**

**Experimental Investigations on Reaction Between Steam and Iron.** K. Wickert and H. Pilz. *Werkstoffe und Korrosion*, **I**, 56-64 (1950). *Chem. Abs.*, **44**, 4843 (1950).

Apparatus is described for conducting tests on reactions of various types of steel with steam, in order to elucidate reactions occurring in steam boilers. The temperature at which iron and steam begin to react in a number of steels ranged from 410 degrees for a low-carbon steel to 780 degrees for a chromium-nickel steel plate. With steels in the form of fine filings of powders, temperature of beginning of reaction was lower by about 100°, exact variation being determined by particle size.—INCO.

**4.6, 7.1**

**Water Conditioning Requirements for Diesel Locomotives.** J. F. Wilkes. Dearborn Chem. Co. Paper before Midwest Power Conference, April 5-7, 1950. *Proc. of the Midwest Power Conference*, **12**, 338-350 (1950).

The paper treats all phases of water conditions for the Diesel engine including the effect of dissolved minerals, cooling water requirements, correction of corrosive tendencies and control of pH in water for Diesel engine cooling systems. It contains a discussion of the function of chromium type corrosion, inhibitors and cooling system corrosion in regard to corrosion-erosion, cavitation and differential aeration attack, electroylsis or galvanic corrosion, dissimilar metals in cooling systems and oil contamination. Chromium test methods, colorimetric comparison, conductivity measurements and chromium spot test method are outlined in considering the control of cooling water treatment dosage. Use of anti-freeze solution, cooling water for stationery Diesel engines, water conditioning for Diesel steam generators, methods for conditioning steam generator feedwater and washing and descaling steam generator coils are also taken up. 9 references.—INCO.

**4.6, 1.4, 4.5**

**The Corrosion of Zinc and Zinc Alloys in Sea Water, Brine and Other Aqueous Solutions and in Soils. A Short Bibliography, 1929-46.** Zinc Development Association. Typescript, 10 pp. (1949).—BNF.

**4.6**

**Water Pollution Research.** Dept. Sci. Indust. Research, Rep. Water Pollution Research Board for the Year 1947, 53 pp. (1949).

Includes an account of experiments on the "Effect of Chlorine on Corrosion of Metals by Water," pp. 5-9; "Waste Waters Containing Cyanide," pp. 47-50; and "Toxicity of Chlorinated Sewage Effluents."—MA.

**4.6, 3.4, 3.3**

**Corrosion of Steel Pipe by Chlorinated Seawater at Various Velocities.** V. B. Volkening. Dow Chemical Co. Paper before NACE, 5th Ann. Mtg., Cincinnati, April 11-14, 1949. *Corrosion*, **6**, No. 4, 123-128 (1950) April.

Corrosion rates of steel pipe in sea water were obtained for six residual chlorine concentrations ranging from 0-4.0 ppm at fiive sea water velocities from 0.1-6.4 ft. per second. Pitting rates were accurately measured and compared with weight loss corrosion data. The minimum effective dosage of chlorine was determined for elimination of marine fouling organisms. A simple accurate method for the determination of residual chlorine in sea water is discussed.—INCO.

**4.6**

**Electrochemical and Chemical Corrosive Attack by Oxygen.** F. Todt. *Werkstoffe u. Korrosion*, **1**, 244-247 (1950) June-July.

Sets forth new theory dealing with disappearance of protective oxide skin (through cathodic reduction). Paper is illustrated by experiments on iron, platinum, cadmium in concentrated salt solution.—INCO.

**4.6**

**The Current Derived in Galvanic Elements by Oxygen Supply as a Measure of the Oxidation and Initial Corrosion of Metals.** (In German) F. Todt. *Werkstoffe u. Korrosion*, **1**, No. 2, 49-51 (1950) Feb.

Nature of oxygen corrosion; investigation of reaction processes at platinum/iron or platinum/cadmium elements in solutions with various oxygen contents by means of current measurements; relation between oxygen concentration and current.—BNF.

## PREVENTIVE MEASURES

### • Cathodic Protection

**5.2, 4.1**

**Physical and Chemical Characteristics of Zinc Anodes for Cathodic Protection.** E. A. Anderson. *Symposium on Cathodic Protection.* Electrochem. Soc. and Nat. Assoc. Corrosion Eng., 97-100 (1949).

Certain chemical and physical constants of zinc are listed and brief details are given on its corrosion behavior in the atmosphere, in natural waters and soils. Information is given on the nature of zinc corrosion products as determined by X-Ray and chemical means. It is stated that very few data are available on the extent of normal corrosion taking place during the electro-chemical dissolution of zinc anodes used for cathodic protection. One set of figures quoted indicates that in a gypsum backfill 89 percent of the zinc lost from the anode is used in producing current to protect the steel and 11 percent is wasted, presumably by normal corrosion. Seven references are appended.—MA.

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**5.2, 8.9, 4.6**

**Cathodic Protection of an Active Ship in Sea Water.** K. N. Barnard and G. L. Christie, Naval Research Establ., Canada. Paper before NACE. Sixth Ann. Mtg., St. Louis (1950) Apr. 4-7. *Corrosion*, **6**, No. 7, 232-234 (1950) July.

Magnesium alloy anodes, weighing about 80 lbs., were secured to the bilge keel but insulated from the steel of the hull of the ship. Hull potential readings with respect to a silver-silver chloride electrode in sea water show that the hull is protected while at rest. Underway the degree of polarization decreases slightly. By securing the anodes to the bilge keel there seems to be a loss in effectiveness caused by uneven distribution of current with varying distances from the anode. Results indicate that cathodic protection of an active ship with an underwater area up to 10,000 sq. ft. is economically practical. Charts.—INCO.

**5.2, 4.5**

**The Corrosion Products on Zinc Anodes Used Underground.** E. A. Anderson, N. J. Zinc Co. Paper before NACE, Fifth Ann. Conf., Cincinnati, (1949) Apr. 11-14. *Corrosion*, **6**, No. 4, 129-131 (1950), Apr.

The presence of sulfates, as gypsum, in the soil around zinc anodes used in the cathodic protection of pipelines was observed to largely prevent the loss of current flow normally found after a time in ordinary soils. It was found that the product adjacent to the zinc was a porous, needle or plate-like mass of crystals of basic zinc sulfate, while the outer layers were a dense, white mixture of the basic zinc sulfate and carbonate. The permeability of the basic zinc sulfate layer accounts for its superior electrical conductivity. An hypothesis for the mechanism of formation of the two layers is given.—INCO.

**5.2, 8.9, 1.7**

**Rapid Wastage of Zinc Protectors on H.M.S. Brecon.** Admiralty Corrosion Committee. Hull Corrosion Sub-Committee, ACSIL/ADM/49/424, Report No. ACC/H223/49. *J. Brit Shipbuilding, R. A.*, **5**, No. 4, 244 (1950).

Because of the enforced undocking of this ship before the hull could be repainted, the zinc protectors suffered rapid wastage. On immersion, they reduced the higher oxides of iron present as rust. The process was in effect similar to electrolytic derusting in which the current was provided by the corroding zinc.—RPI.

**5.2, 4.2, 4.6**

**Sprayed Metal Coatings Improve Corrosion Resistance of Wide Range of Products.** John E. Wakefield. *Materials & Methods*, **31**, 67-69 (1950) Apr.

Surveys use of metallizing for applying corrosion-resistant non-ferrous coatings. Presents tabular data on costs, rates of application, and life expectancies. Information deals with zinc, auminum, tin and lead with emphasis on the first two. Covers rural, industrial and marine atmospheres, as well as fresh and salt water.—BLR.

**5.2**

**Use of Rectifiers as an External Source of Protective Currents for Cathodic Protection.** F. A. Waelterman. Symposium on Cathodic Protection. Electrochem. Soc. and Nat. Assoc. Corrosion Eng., 73-76 (1949).

The characteristics of the selenium rectifier are described and some observations are made on rectifier design and on specifying rectifiers.—MA.

**5.2, 3.6, 4.5**

**Current Output of Light-Metal Galvanic Anodes as a Function of Soil Resistivity.** E. D. Verink, K. K. Reid, and E. R. Diggins. Symposium on Cathodic Protection. Electrochem. Soc. and Nat. Assoc. Corrosion Eng., 101-103 (1949).

The importance of being able to predict with reasonable accuracy the current output of individual units in a cathodic-protection system is stressed. Methods by which the current output of galvanic anode installations may be predicted are proposed. The mathematical development presented is evaluated by means of field data from test installations at several locations. It is shown that soil resistivity is an important factor in predicting current output. Two references.—MA.

**5.2, 7.7**

**Electrolysis Experiences on 115 KV High Pressure Oil Filled Pipe Type Cable Installation in New Orleans.** S. E. Trouard. *Corrosion*, **6**, No. 2, 66-71 (1950) Feb.

A report on a detailed study of the electrical characteristics of a coated steel-cased line installed in a region where many stray currents occur. The line, 11 miles long, was connected to a number of zinc anodes both to afford cathodic protection and to protect workmen from high voltages which might arise in the event of power faults. At some points these measures were inadequate and the potential had to be adjusted by connections to other structures and to a railway system.—ZDA.

**5.2, 8.9**

**Cathodic Protection by Magnesium Anodes: A Method for Preventing and Arresting Corrosion of Pipelines.** W. G. Waite. *Brit. Constructional Engr.*, (1950) May.—BNF.

**5.2, 8.9**

**Cathodic Protection and its Application to the Iraq Pipelines.** W. C. R. Whalley. *J. Inst. Petro.*, **35**, No. 310, 705-734 (1949) Oct.

After a general discussion of cathodic protection of pipelines, author considers current sources, ground beds (back fill materials), protective coatings and the development of the cathodic protection system for the Iraq line. Magnesium anodes were found to be impracticable in the desert but successful in coastal areas, and finally rectifiers were used for one section of the line and automatic Diesel generator sets for another. A copper/copper sulfate electrode for measuring pipe/ground potentials is described.—BNF.

## • Metallic Coatings

**5.3, 3.5**

**The Chromatizing of Iron.** H. Buckle. *La Recherche Aeronautique*, **1950**, 61-62, July-Aug.

The diffusion of chromium into iron produces two phases, viz., an $\alpha$-phase, forming the core and rich in iron, and a $\gamma$-phase, rich in chromium. These two phases require two different diffusion

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coefficients, whose numerical calculation for diffusion temperatures from 900° to 1200° C is the object of the present study. The theoretical values show good agreement with empirically obtained data and bear out the validity of the method.—TDD.

5.3

**Periodic Reverse-Current Electroplating.** Adolph Bregman. *Metal Prog.*, **58**, 199-200 (1950), Aug.

Gives details of Jernstedt's "PR" process for making electroplates smooth enough to require no buffing or polishing. Includes information on three types of equipment, and on copper, silver, zinc, cadmium, gold, and nickel plating baths. Surveys applications, summarizes advantages, and presents cost data.—BLR.

5.3, 2.3

**Specifications and Tests for Electrodeposited Metallic Coatings.** American Society for Testing Materials. 53 pp. (1949) Oct.

A compilation of the 12 ASTM Standards and Tentative Standards relating to plated coatings. They include A164-49T, Electrodeposited coatings of zinc on steel; A165-49T, Electrodeposited coatings of cadmium on steel; B142-45T, Electrodeposited coatings of nickel and chromium, on zinc and zinc-base alloys; B201-49T, Chromate finishes on electrodeposited zinc, hot-dipped galvanized, and zinc die cast surfaces; A219-45T, Tests for local thickness of electrodeposited coatings; and B117-45T, Methods of salt spray (fog) testing.—ZDA.

5.3, 5.9, 1.2

**American Welding Society (Tentative) Recommended Practices for Metallizing. Part IA.—Metallizing Shafts or Similar Objects. Part II.—Metallizing—Safety Recommendations.** 9 x 6 in. pp. iv + 20, with 11 illustrations. 1950. The Society, 33 West 39th Street, New York 18. 75 cents.

This standard, the first of a series on metallizing to be issued by the American Welding Society, covers all methods of surface preparation, metal-spraying procedures and finishing of sprayed metal shafts or similar objects, together with safety recommendations to be followed in metallizing operations.—MA.

5.3

**The Theory and Practice of Hot-Dip Galvanizing.** Heinz Bablik. *Metalloberflache*, [A] **3**, No. 5, 105-110 (1949).

B. reviews and summarizes recent work (mainly his own), on hot-dip galvanizing. Subjects covered are: 1. fluxes and their effects; 2. the structure of the coatings produced, in relation to a) the carbon, silicon and titanium contents of the steel, b) the aluminum, antimony, cadmium, copper, iron, lead and tin contents (as impurities or additions) of the baths; 3. the lead-zinc process; and 4. the corrosion of galvanized containers used for preparing pig food.—MA.

5.3, 5.4

**Tin Coatings on Steel as a Basis for Protective Painting.** S C. Britton. *J. Oil & Colour Chemists' Assoc.* **33**, 125-134; disc. 134-136 (1950), Mar.

Surveys methods of applying tin coatings; corrosion resistance; adhesion of paint films to tin coatings; and the mode of action of tin under paint. Includes illustrations of exposure and adhesion test specimens. 11 ref.—BLR.

5.3, 2.2, 4.2, 1.7

**Report of Committee B-8 on Electrodeposited Metallic Coatings.** American Society for Testing Materials, Philadelphia, Pa., Preprint 15, 30 p. (1949).

Results of atmospheric exposure tests of steel electroplated with lead, and high-carbon steel electroplated with copper-nickel-chromium are reported by subcommittee II.

Steel specimens electroplated with lead were exposed at four different locations for 4.3 yr. The extent of damage to the steel base, determined by measuring weight loss, was confirmed by visual inspection and by elongation, yield strength, and tensile strength tests, and the following summary was made.

1. Among the several atmospheres, lead coatings varied widely in protectiveness.
2. The corrosivity of an atmosphere toward bare steel has no direct bearing on the effectiveness of lead coatings.
3. Visual inspection indicates that at all locations, damage to the steel base varies inversely with coating thickness.
4. The protectiveness of lead coatings is directly related to the corrosion rate of lead in the various atmospheres.
5. The thickness of lead required to protect steel for a given time varies with place of exposure.
6. For thicker, more protective coatings, a 0.000015-in. undercoat of copper plate is beneficial.

A preliminary analysis of somewhat incomplete data obtained from the in-

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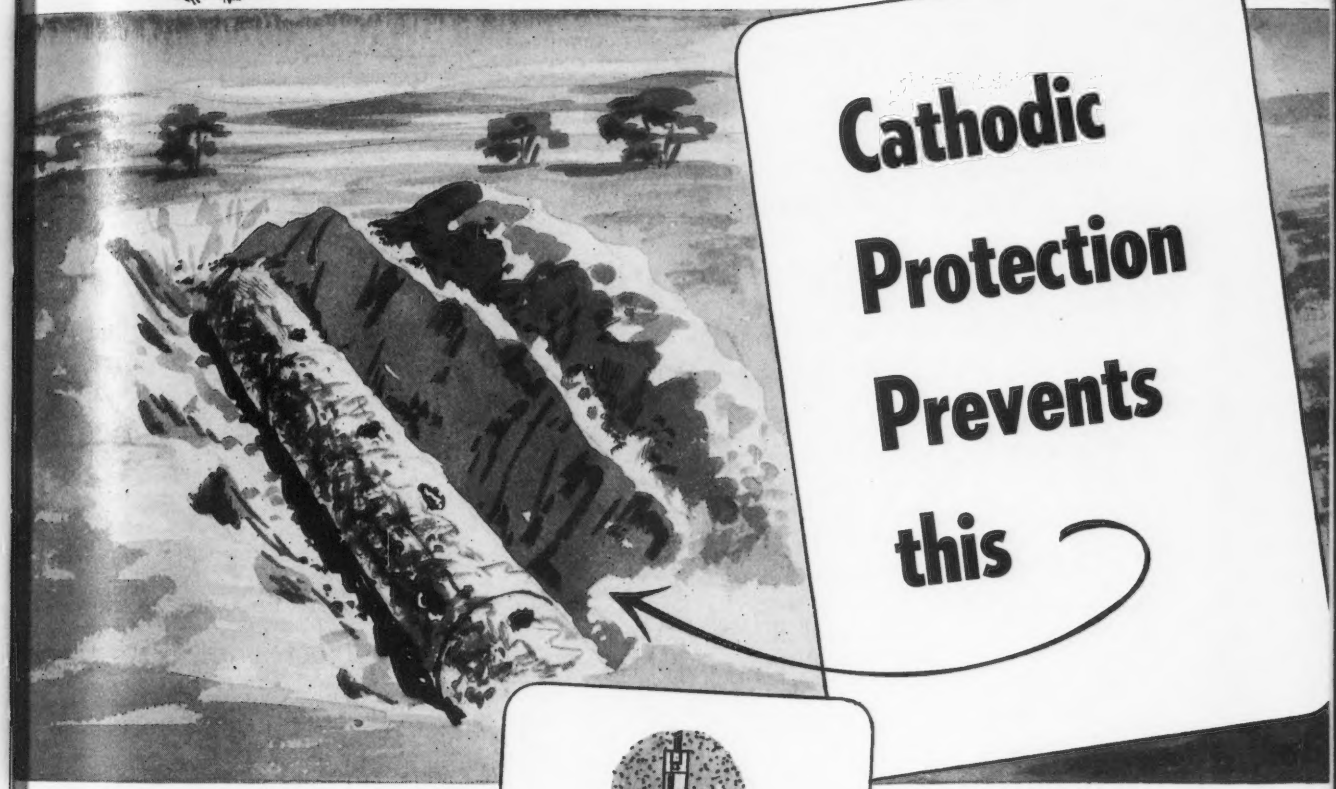

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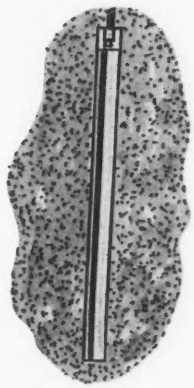

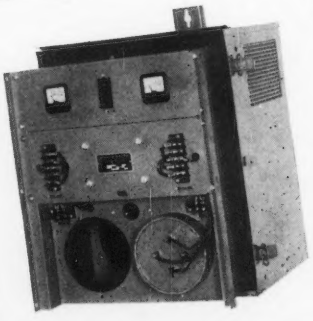

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spection of various composite copper-nickel-chromium electrodeposits on high-carbon steel exposed for about 14-18 months to various atmospheres leads to the following conclusions:

1. Rate of deterioration of the various deposits is markedly affected by the type of atmosphere.
2. The high-carbon steel base is neither more nor less susceptible to protection than low-alloy steel of high yield strength.
3. The thickness of the copper undercoating is not an important factor.
4. The type of nickel plate exerts no important influence on coating life, but the thickness of the nickel layer is very important in determining the atmospheric weathering characteristics of the composite coating.

Rating numbers of from 10-0, based on the percentage of defective area, were assigned by visual examination aided by photographic standards.—PDA.

5.3, 8.8

**When and How to Line Process Vessels with Stainless Steel.** R. G. Sloan, Jr. *Chem. Eng.*, **57**, No. 3, 117-121 (1950) Mar.

The advisability of stainless-clad or solid stainless vessels and the wall thickness of each for the chemical industries is discussed. Plug, strip and spot welding of the clad steel and the advantages of each is described.—INCO.

5.3

**Metallic Coatings. I. (Chemical) Dipping Process.** (In German). W. Wiederholt, FIAT. *Rev. German Sci.*, 1939-1946; *Ferrous Metallurgy*, **II**, 279 (1948).

A brief note. Dipping processes are suitable only for the production of decorative films of copper, gold, silver and tin on iron and steel; the coatings are too thin to give any degree of corrosion protection. 6 references.—MA.

5.3

**A Tabulation of Electrolytic Metal Finishing Processes.** A. Whittaker. *Mech. World*, **127**, No. 3297, 332-333 (1950) March 24.

A table outlining the characteristics and applications of metals which are commonly electro-deposited. Zinc is stated to have high corrosion resistance and high throwing power, and to be cheap to deposit. Cadmium gives very ductile deposits, but has poor acid resistance and is expensive to use in spite of its fast rate of deposition.—ZDA.

5.3

**Developments in Galvanizing.** F. G. White. *Prod. Fin.*, **14**, No. 8, 48, + (1950).

An historical review of the development of hot-dip galvanizing.—MA.

5.3

**Stop Corrosion with Sprayed-on Zinc.** John E. Wakefield. *Refrig. Eng.*, **57**; 982-5 (1949).

The application of thin coatings of zinc or aluminum to steel or iron provides physical and electrochemical protection. The metallizing gun and methods of applying the coatings are described.—RA.

5.3

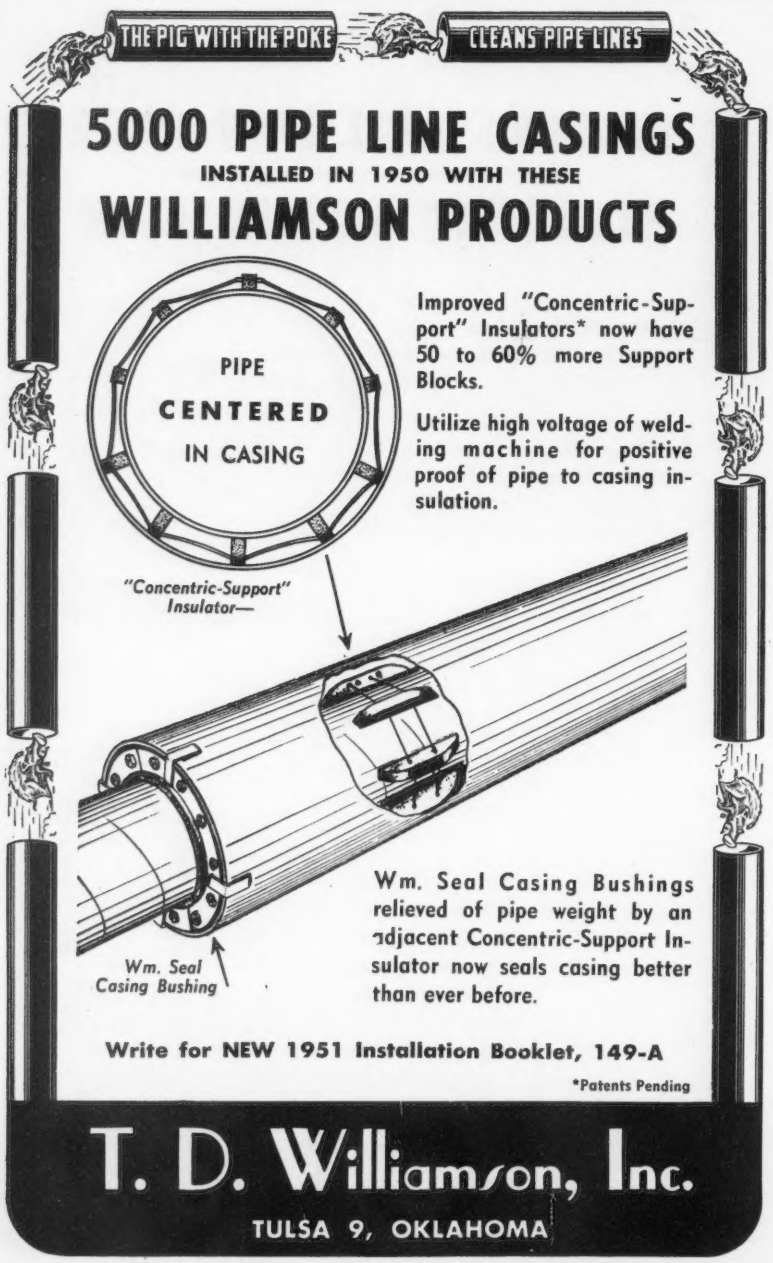
**Nickel Immerson Coatings by Electrochemical Displacement and by Chemical Reduction.** W. A. Wesley, (Inco). Bayonne Tech. Paper No. 175, Oct. 6, 1949 *Plating*, **37**, No. 7, 732-734, + (1950) July.

The displacement method does not require equipment for high temperature annealing in a nonoxidizing atmosphere. It can be used to produce only thin nickel or nickel-iron coatings less than 50 millionths inch thick on a steel or iron base. The nickelized steel produced by the displacement process is suggested as an inexpensive superior base for other coatings, such as ceramic enamels, organic finishes, conversion coatings and perhaps other metallic coatings. The electroless process can be used to apply coatings as thick as several mils to a variety of bases, including steel, copper, brass, aluminum and nickel. Due to costliness of the reducing agent, sodium hypophosphite and the rather low efficiency of its use, electroless coatings can compete with electroplated nickel only for special purposes. The electroless nickel deposit is not pure nickel but contains phosphides which may prove to be an advantage depending upon the proposed use. Large amounts of phosphide in nickel may alter its corrosion resistance although the behavior in salt-spray and ferroxyl tests is normal. With high phosphorous content nickel is nonmagnetic, which property may be useful in special cases.—INCO.

5.3

**Metal Spraying of High-Temperature Metals and Alloys.** R. T. Thurston and F. Wulff. *Welding J.*, **29**, 313, + (1950) July.

This paper describes the spraying of high-melting point metals and alloys, the properties of the deposits and the densi-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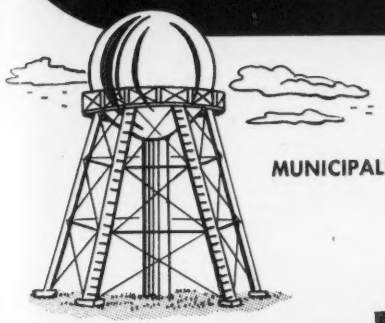

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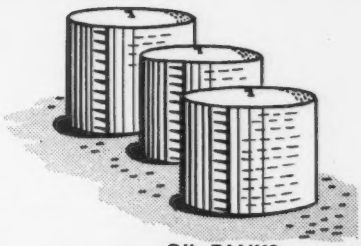

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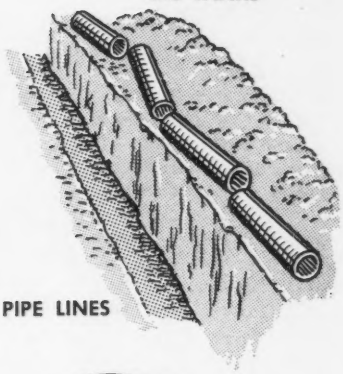
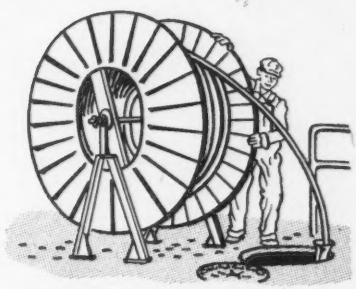


PIPE LINES



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fication achieved by sintering. The materials reported include molybdenum and nickel, molybdenum-nickel alloys and three commercial high-temperature alloys, Hastelloy C, Vitallium and CM 469 (containing 60 percent chromium, 25 percent molybdenum and 15 percent iron). A deposit of sprayed molybdenum was found to be composed of layers of molybdenum metal which are separated by voids and oxide. This is typical of sprayed metals in that a lamellar structure is formed in which oxide is entrapped between layers of metal. To determine the effect of the oxide content of sprayed metal upon its strength a special hydrostatic bursting apparatus was developed. Since the strength of sprayed metals is largely affected by the amount of oxide and the number of voids they contain, sintering in hydrogen at elevated temperatures was carried out to improve the strength of sprayed deposits. Even though sintering of sprayed molybdenum resulted in improved properties, sintering in the presence of a liquid phase gave a further improvement. To achieve a liquid phase during sintering of sprayed molybdenum deposits, small amounts of nickel were added by different techniques. A coating of nickel was first sprayed on the top of the coating of molybdenum. Although some liquid phase was then formed when the composite was sintered, its passage into the molybdenum deposit was limited. The most successful technique was to paint or spray a deposit of molybdenum with successive coatings of a solution of very fine nickel metal powder or nickel salts suspended in alcohol. The porous deposit absorbed in the suspension and distributed the nickel throughout the spray coat.—TIME.

5.3

**Factors Affecting the Production and Properties of Hot-dipped Galvanized Coatings.** R. W. Thorley. Brit. Non-Ferrous Metal Research Association, Report RRA 868. 44 pp. (1950) Jan.

A review of literature on the galvanizing process with special reference to the effects of impurities and of alloying additions in the bath. Although much of the literature is conflicting, the author is able to draw various conclusions from it. The field covered by the survey includes the metallography of coatings and the attack of molten zinc on iron and its alloys, the resistance of the coating to deformation, its external appearance, the oxidation of the zinc bath and the drainage of zinc from hot-dipped articles.—ZDA.

5.3

**Sherardized Strip.** H. H. Symonds. *Met. Ind.*, **76,** No. 13, 247 (1950) Mar. 31.

A concise report on an investigation into the cause of some defects in Sherardized steel strip. The defects showed as spots of rust and zinc corrosion products and resulted from the action of standing moisture. The specimens were examined micrographically, by the copper sulfate test and by a bending test. It was found that the faulty strips had only a very thin brittle coating of zinc, easily attacked by residual moisture.—ZDA.

5.3

**Aluminum Coating of Steel—A Comparison of Various Processes.** P. T. Stroup and G. A. Purdy. *Metal Prog.*, 57, 59-63, + (1950) Jan.

Steel can be coated with aluminum by hot dipping, cladding, electroplating, spraying, chemical reaction, and calorizing. Importance of controlling the thickness of the iron-aluminum compound that forms between the base metal and the coating. The six methods of coating are compared on the basis of structure and cost. 29 references.—MR.

5.3

**Preparing Cast-Iron Surfaces for Bonding.** J. H. Shoemaker. Sleeve Bearing Materials, Amer. Soc. Metals, 199-205 (1949).

Describes two methods for preparing cast-iron surfaces so that a uniform bond between the bearing material and the cast iron is obtained. The first consists of sand or grit blasting to remove surface sand and scale followed by immerson in a molten salt bath at 825-950° F (440-510° C) for 5-15 min. The casting is then immersed in a reducing bath, rinsed, immersed in 10 percent hydrochloric acid, fluxed, and immersed in a molten bath of a suitable tinning metal. The second method consists of immersing the casting in a bath of catalyzed molten salt at 825-950° F (440-510° C) and then applying a voltage, making the casting the cathode. This exposes graphitic carbon which can be removed by reversing the flow of current. The thin oxide film formed is removed by reversing the current again, and then the casting is rinsed in water, fluxed, tinned and the bearing material put on.—MA.

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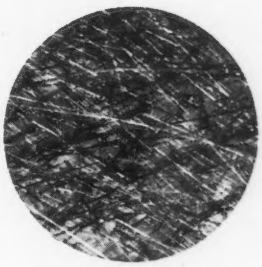

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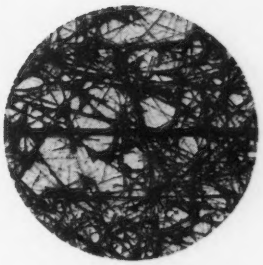

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## • Non-Metallic Coatings & Paints

5.4, 6.6

**Chemistry of Western Pines. Pine Knots and Paint Durability.** A. B. Anderson. *Ind. Eng. Chem.*, **42**, No. 3, 565-9 (1950).

The chemistry of the acetone extract of red knots from three Western U.S.A. pines (Ponderosa, sugar and Idaho white pines) was investigated in relation to discoloration of white paints. The extract was fractionated into a neutral fraction and five sodium hydroxide-soluble fractions and the effect of the fractions on the color of white lead paints and a white N. C. lacquer was studied. On exposure to a mercury lamp most discoloration was produced by the petroleum-ether-insoluble phenolic constituents. Phenolic resin varnish (10 pts.) + polyvinyl butyral (1 pt.) in ethyl alcohol (19 pts.) was found to be a satisfactory sealer over knots.—RPI.

5.4, 2.3, 7.2

**Behavior of Bituminous Pipe Coatings Under Bending Vibrational Stress.** W. Beck. *Corrosion*, **5**, No. 12, 405-8 (1949).

Bituminous pipe coatings applied on a steel pipe were subjected to cycles of vibrational bending stresses, at 10 c/s, and varying temp. Crack formation was detected electrically. Low temp. and heavy traffic vibrations will hence cause failure of coatings on underground pipe lines.—RPI.

5.4, 8.4

**Fiberglas Strips Save Crude-Oil Storage Tanks.** *Bus. Week*, No. 1094, 42 (1950) Aug. 19.

The corrosion and fouling of crude oil storage tank bottoms by water and sulfur products pumped in with the oil can be prevented by covering the tank bottom with overlapping strips of "Coromat" Fiberglas impregnated with a tarry binder. The tank bottom is first sand-blasted and enameled; a second coat of enamel is applied after the Fiberglas is laid. The method, developed by Industrial Service Co., saves about $1500 per tank in service costs plus the costs of the 50 tons of steel sometimes needed to replace a tank bottom.

## INDUSTRIES

## • Group II

8.2, 5.4

**Corrosion Protection of Power Transformers by Flow Coat Method.** S. L. Miller, Union Electric Co., Mo. Paper before NACE, 5th Ann. Mtg. Cincinnati, April 11-14, 1949. *Corrosion*, **6**, No. 6, 144-147 (1950) May.

The results of 10 years of experimentation with the corrosion protection of power transformers by the flow coat method of applying stripping media and protective coatings is discussed. The advantages and possible disadvantages with respect to economy from the standpoint of time required are presented. Adequate protection of the uniform thickness is easily attained by this method.—INCO.

## • Group III

8.3, 6.4

**Corrosion Characteristics of Light Metals Used in Sprinkler Irrigation Systems.** *Light Metal Age*, **7**, No. (5/6) 14-15, + (1949).

A summary of a report published by the Washington Institute of Technology.—MA.

8.3, 5.3

**Hard Chrome Plating and Avoidance of Metal Pick-up.** M. A. Joslyn. *Wines & Vines*, **31**, No. 4, 67-69 (1950) Apr.

A review of the metals used in the wine industry is given. Searle, LaQue and Dohrow in 1934 concluded that Inconel is adequate for all winery uses and that nickel, Monel, 18-8 stainless steel, aluminum and copper were adequate except in equipment in which the relation between liquid volume and exposed metal area was unfavorable. Stainless steels, Inconel and aluminum alloy 76 were most corrosion resistant. The velocity of flow of wine over metal surface, temperature, extent of aeration, composition of wine, especially its acidity, sulfur dioxide content and pigment content are important factors governing corrodibility as well as mechanical strains and actual physical and chemical changes induced by fabrication. Tolerances for metals as chromium, nickel, copper and iron are given. Processing equipment is chrome plated with a nickel undercoat because it is non-corrodible and friction resistant. Steel, cast iron and copper and bronze can be successfully plated and used.—INCO.

8.3, 7.5, 6.4

**Fresh Fish in Aluminum Containers.** *Food Manuf.*, **25**, No. 3, 98-100 (1950).

A new procedure designed to preserve the freshness of fish for retail distribution, involving the packaging of fresh filleted fish in aluminum containers is described. The pack has been found to respond well to exhaustive transport tests and is easily opened by cutting the lid with a knife. The ultimate aim is the packaging of fish at sea.—MA.

8.3, 6.4

**Advantages of Aluminum for Milk Transportation.** E. Kohn-Abrest. *Annales des Falsifications et des Fraudes* (France), **42**, 161-165 (1949); *Met. Asbst.* (England), **17**, Part 7, 541 (1950) Mar.

The likelihood that aluminum will be corroded in use depends very little on its impurities, but it requires absolute cleanliness and is not suited to liquids containing salt. It is not altered by milk, but is quickly corroded by rum.—ALL.

## • Group IV

8.4, 5.3, 5.4, 5.2

**Protection of Steel in Off-Shore Structures.** F. L. LaQue. *Drilling*, **11**, 29-31, + (1950) June.

Describes cathodic, Monel facing and paint protection for various sections under water and underground. Includes schematic diagram and illustrations.—BLR.

8.4, 6.2, 3.5

**Cast 12% Chrome Steels Proved in Gas Wells.** J. W. Juppenlatz. *Iron Age*, **165**, 85-89 (1950) June 22.

Gas well Christmas tree fittings made of cast 12% chromium alloy steel were found to be the ideal solution to severe corrosion encountered by the gas-condensate industry. Attack is by a mixture of organic acids plus carbonic acid. Conditions of high pressure, relatively high reservoir temperature, and turbulent flow causing erosion require an unusual combination of properties. Data for a variety of alloys are tabulated and charted. Typical corroded and eroded fittings are illustrated.—BLR.

8.4

**Corrosion Problems in Gas Purification Units Employing Monoethanolamine Solutions.** F. C. Risenfeld and C. L. Blohm. *Petro. Ref.*, **29**, 141-150 (1950) Apr.

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on corrosion of carbon, alloy, and stainless steels; and of aluminum and its alloys in contact with aqueous solutions of monoethanolamine or mixtures with diethylene glycol and water. Such solutions are used to remove carbon dioxide and hydrogen sulfide from flue gas, hydrogen, and refinery and natural gases. Test equipment is diagrammed. Results are charted and tabulated.—BLR.

**8.4, 5.3, 5.4**

**Preservation of Gas-Works Structures by Paint.** L. A. Ravald. *Gas*, **3**, No. 27, 156-74 (1948); *ZDA Abs.*, **7**, No. 12, 177 (1949).

The author's experiences in the use of paints based on drying-oils for protecting the outdoor structures of gas works are presented. The ideal pre-treatment for new steel work is to coat it with zinc by hot-dipping or other processes. Pickling or shotblasting, followed by one coat of red lead primer, is a cheaper process where large areas are involved. Preparation of the surface for repainting and repainting of water-sealed gas holders are discussed, followed by consideration of suitable paint compositions. Red lead is the most effective primer pigment when used in linseed oil media, but zinc powder incorporated in a non-hydrophilic medium is also recommended. The most suitable pigments for finishing paints on gas-works are zinc oxide and chromium oxide, together with red and brown ferric oxide, ochre and silica graphite. Zinc surfaces, when properly prepared, provide a good basis for paint. —RPI.


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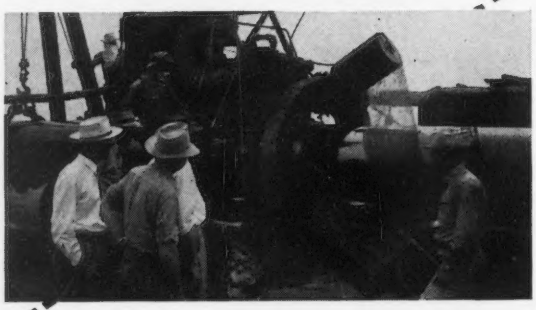

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**8.4, 4.6**

**Corrosion in Water-Flood Operations.** F. A. Prange. *World Oil*, **130**, 157-158, 160 (1950) Apr.

Discusses types of corrosion, choice of alloys for above oil-field operations, and preventive measures.—BLR.

**8.4, 5.4**

**Corrosion in the Gas Plant: Its Causes and Prevention.** E. O. Rhodes. *Gas*, **25**, No. 12, 32-37 (1949); *C. Abs.*, **44**, 820 (1950).

In general, corrosion-resistant alloys would be satisfactory for many gas-plant uses, but are too expensive, so that protective coatings must be used instead. Metal parts that come in contact with calcium chloride solutions used for dedusting domestic coke are best made of stainless steel; aluminum can be used, but is subject to pitting. Ammonia liquor coolers are best of the shell and tube type; with corrosive cooling water, the water side of the tubes may be lined with copper. Exhausters are subject to little corrosion, except that on standby use slight atmospheric corrosion of the interior may cause imbalance and vibration. They should be filled with coke-oven gas while idle. Ammonia saturators are now built of Type 316 stainless steel. All of the sulfur-removal processes have corrosion problems; coal-tar coatings are promising here. Heavy protective coatings are required on the interior and exterior surfaces of the flushing-liquor decanting tanks. Ammonia stills are best made of cast iron; Monel has been successfully used in the reboiler sections of the dephenolizer. All pumps, valves, centrifuge baskets, etc., coming in contact with ammonium sulfate crystals should be of Type 316 stainless steel. In refining light oils, Monel is used for agitators and valves; exterior surfaces of the refining equipment are protected with acid-resisting enamels. In general, wide use is made of synthetic resin coatings on exterior surfaces, and heavy-duty coatings, frequently of the coal-tar type, on interior surfaces.—MA.

**8.4, 6.4, 8.9**

**Light-Alloy in the Petroleum Industry —I-IV.** *Light Metals*, **12**, No. 134, 131-133; No. 135, 196-202; No. 136, 284-289; No. 137, 335-344 (1949).

I. A description is given of the plant involved in the production, refining, and distribution of crude oil, with a consideration of the possible application of aluminum in this field. II. A review of the possibilities of light alloy oil pipelines is made, with a comparison between steel and light alloys from the point of view of resistance to chemical attack, physical properties, welding, and cost. III. The use of aluminum alloys in refinery equipment is surveyed, with particular reference to corrosion resistance. IV. The use of sprayed aluminum coatings and aluminum paint is discussed. The use of aluminum for condenser tubes and heat exchangers is also considered.—MA.

**8.4, 5.3, 5.4, 6.5**

**Corrosion Resistant Liners in Refinery Vessels.** G. C. Carpenter, Esso Standard Oil Co. Paper before ASME, Petroleum Mech. Eng. Conf., Oklahoma City, Oct. 1949. *Petro. Ref.*, **29**, No. 7, 95-103 (1950) July.

Leaks in the corrosion-resistant liners of 18-8 stainless steel, 13 chromium steel, and Monel plug, strip, lap and fillet welded are compared. Plug welding is the least desirable. Narrow strips ¾-

inch wide of ferrous alloy metal should be butt welded for high temperature service. Alloy liner material 18-8 stainless steel, Hastelloy B, Inconel, lead, brass, glass and plastic coatings are compared. 18-8 stainless steel liners are used for sulfide corrosion at high temperature. Monel is satisfactory here at medium and low temperature service. Inconel is used to combat both general corrosion and stress corrosion cracking at caustic injection points in crude processing units. Hastelloy B is used in acid pump casings as a welded-in or deposited metal. Hastelloy B sheet is a good strip liner in hydrochloric acid and sulfuric acid service. Plastic coatings offer much promise as liners in atmospheric temperature service provided they are properly applied. Charts. Photographs.—INCO.

8.4

**Continental Expands Ponca City Refinery.** N. Horton and W. Kolar, Continental Oil Co. *Oil & Gas J.*, **48,** No. 28, 72-74+ (1949) Nov. 27.

Anhydrous $NH_3$ is injected above top tray of main fractionator to reduce corrosion in overhead lines and condenser system. Tube headers in heaters, tubes, tube sheets and channels in exchangers operating between 450-550° F are of 4-6 chromium, 0.5 molybdenum. Tubes in the radiant section of the heater, as well as piping and exchangers operating above 550° F, are of 7 chromium and 0.5 molybdenum. Main fractionator is Monel clad from its top to the tenth tray. Remaining portion of tower, as well as gas-oil and distillate stripping towers, is clad with 11-13 chromium alloy. Carbon steel heater tubes and fittings were replaced with chromium alloy. To provide corrosion protection against sour gas-oil charge, the tar stripper, the reactors, and the bottom 27 ft. of the fractionator were lined with 11-13 chromium material.—INCO.

8.4

**Operating Problems in Gas Treating for Hydrogen Sulfide Removal.** J. S. Connors and A. J. Miller. *Petro. Proc.*, **5,** 29-31 (1950) Jan.

Many corrosion and other operating problems connected with the above are also experienced by petroleum refiners in treating refinery gases from sour crude. The treating methods described are applicable in a technical sense, although different economic factors would prevail for the refinery application. The modified iron-oxide process is being used in treating natural gas where the $H_2S$ content is low.—BLR.

8.4, 5.9, 5.4

**Notes on a Refinery Paint Programme. I-II.** W. B. Cook. *Petro. Ref.*, **28,** No. 2, 155-60, No. 3, 115-19 (1949); *Chem. Abs.*, **43,** No. 18, 7237d (1949).

A brief review of surface preparation, general painting practices, primers, and top coatings. Priming and finish coatings for high temp., corrosive atmospherics and tank interiors are discussed, in addn. to color schemes. The author recommends an intelligently-planned long-term field application and observation program conducted by technical personnel co-ordinated with refinery maintenance as the proper approach toward max. protection with min. cost.—RPI.

8.4, 6.3

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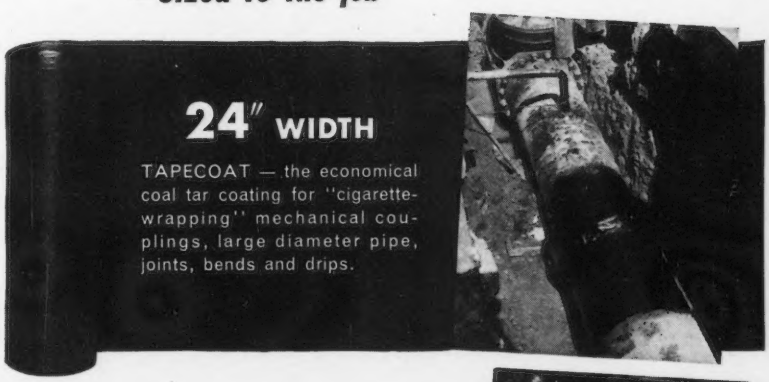

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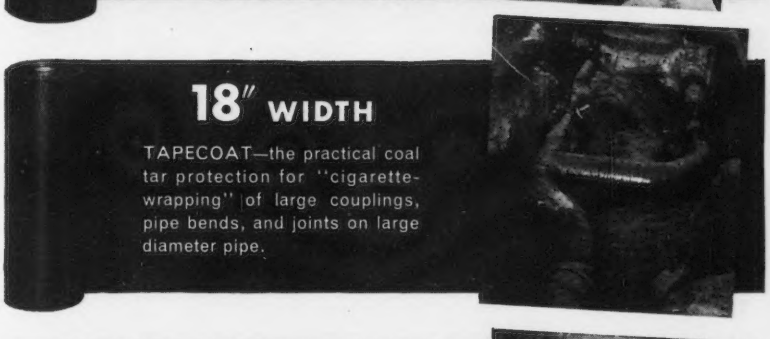

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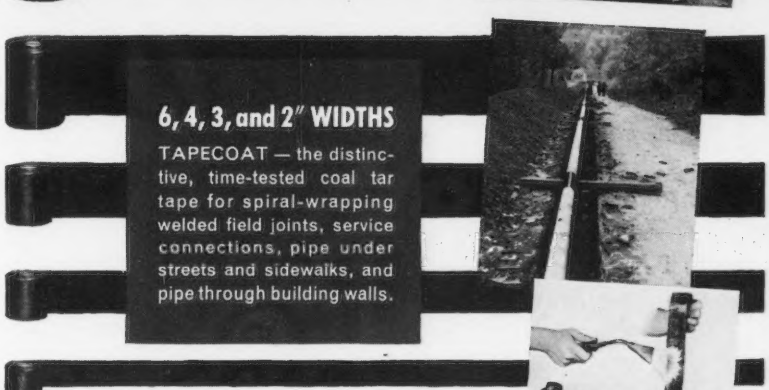

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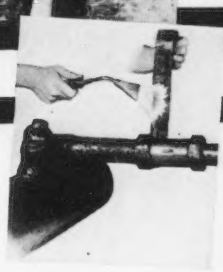

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**shore Drilling. Other Marine Applications.** W. L. Nelson. *Oil & Gas J.*, **48,** No. 37, 74 (1950) Jan. 19.

Of the metals and alloys given sea water corrosion tests at Kure Beach, Hastelloy C has the most outstanding test results so far. A brief description of the test conditions and results lead to the conclusion that it might be used for offshore drilling equipment where large stocks of replacement parts cannot be readily available. Tables are included.—INCO.

## • Group V

8.5, 7.6, 6.2

**Stainless-Clad Steel for Digesters.** W. H. Funk and E. H. Wyche, Lukens Steel Co. *Paper Trade J.*, **130,** No. 20, 23-24, + (1950) May 18.

Several advantages are gained by using stainless-clad steel digesters for sulfate and sulfite pulping. Clean, smooth, corrosion-resistant inner surfaces are beneficial to digesting operations and provide longer trouble-free life for digesters. Lower costs per ton produced are realized due to longer life and increased output per cook. The use of stainless-clad steel instead of a ceramic lining will enable the pulp mill to use fewer digesters of a given size to obtain the desired tonnage. The uniformly smooth stainless steel permits closer and more uniform packing when charging chips. This is probably one reason why digester capacity is increased out of proportion to the calculated volumetric increase. Quick discharge of pulp is facilitated. The selection and application of the proper type of stainless-clad is emphasized. The process of manufacturing clad steel is the "Heat and Pressure Method." The stainless plate has been nickel plated on that surface to be rolled against the carbon steel plate in order to get a clean oxide-free surface for bonding. Type 410 stainless steel has fair corrosion resistance. Type 316 has excellent corrosion resistance, but is subject to intergranular corrosion. Type 316 ELC (18 Chromium, 8 Nickel, 2 Molybdenum, 0.03 max Carbon) has excellent corrosion resistance and is not subject to intergranular corrosion, and is preferred throughout the digesters. Charts.—INCO.

8.5

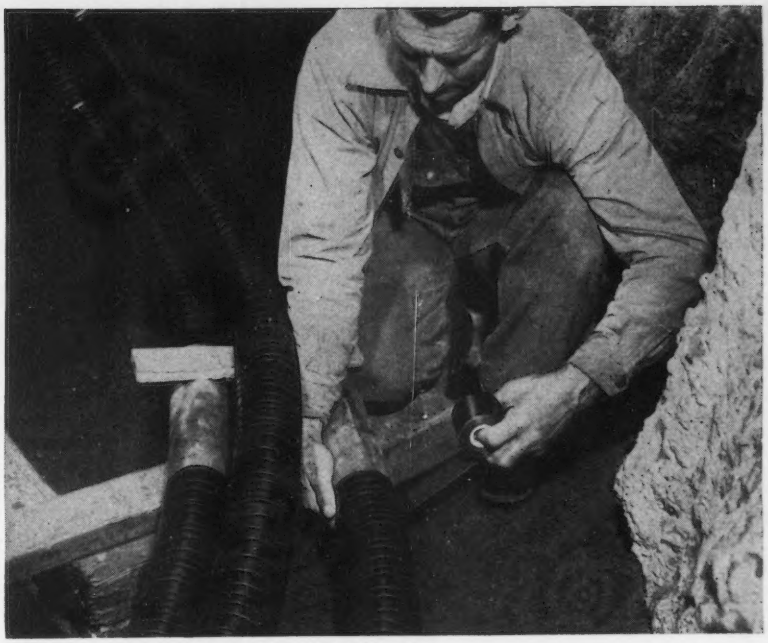
**Corrosion in the Paper Mill.** J. S. Overbagh and W. H. Birchard. *Paper Trade J.*, **131,** No. 4, 26, + (1950) July 27.

Factors affecting corrosion include hydrogen ion concentration, oxidizing agents, temperatures, agitation and erosion, oxidizing, and galvanic corrosion. These factors are discussed in relation to occurrences in paper mill.—INCO.

8.5, 3.2, 2.3

**Corrosion and Corrosion Testing in the Pulp and Paper Industry.** R. A. Huseby and M. A. Scheil, A. O. Smith Corp. Paper before Tech. Assoc. of Pulp and Paper Ind., Portland, Ore., 12015, Sept., 1949. *Proc. Tech. Assoc. Pulp Paper Ind.*, **33,** No. 3, 138-148 (1950) Mar.

General corrosion, pitting (Inconel and 18-8 showed no pitting), intergranular attack, stress corrosion cracking, galvanic corrosion, dezincification and erosion-corrosion are discussed with application to stainless steel in the pulp and paper industry. Remedial measures such as alloy selection and heat treatment are

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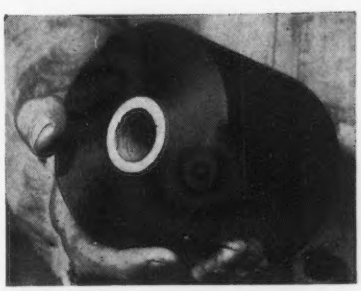

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included. The effect of carbon content on pitting tendency is illustrated. It is shown that increased corrosion resistance in the ammonium bisulfite process can be effected by keeping chromium content of Type 316 analyses on the high side of the range. Metallurgical considerations in fabrication of alloy-lined equipment are discussed. These alloys include 13 chromium-iron, 18-8 columbium, Inconel, Molybdenum-chromium-nickel stainless steel and higher nickel alloys. Illustrations.—INCO

8.5, 6.2

**Stainless Roof Drainage Under Severe Corrosive Conditions.** A. M. Levine. *Sheet Metal Worker,* **41,** No. 10, 46-48 (1950) July.

Type 302 stainless steel roof drainage system is successfully withstanding the severely corrosive atmophere of fumes and steam from paper making processes. —INCO.

## • Group VI

8.6, 5.4

**Preventing Corrosion of Textile Machinery-Research at T.M.M.'s Helmshore Laboratories.** *Indian Text J.,* **60,** 128-30 (1949) Nov. *Text. Tech. Dig.,* **7,** 240 (1950). *NPVL Abs.,* No. 158, 113 (1950).

The best and most economical methods of preventing corrosion of textile machinery are discussed. A three-coat process which is used primarily on machinery that is to be stored and another process using a single coat of a transparent plastic applied by hot dipping, are described.—RPI.

8.6, 4.6, 5.7

**Textile Process Water Problems and Control.** E. T. Laurin, Calgon, Inc. *Rayon & Synthetic Textiles,* **31,** No. 5, 103-105 (1950) May; No. 6, 81-82 (1950) June; No. 7, 81-83 (1950) July.

Water used throughout the processing operations must be treated to control corrosion. Water passing through iron pipes picks up 1-4 ppm of iron. Oxygen and carbon dioxide in the water will cause corrosion of the pipe lines and bring iron into solution. The carbon dioxide is removed by heating or by treatment with lime. Water for woolen, cotton and rayon mills can be softened with Calgon to remove calcium, magnesium and iron salts that damage fibers and occlude dyes. A water softener in the water for hosiery mills will prevent dye-resistant soap spots from forming on the fibers and will disperse the pigments in the delusterant finishing. Methods of hardness testing are given. Calgon can control corrosion in addition to its water softening function. The Calgon forms a mononuclear film on the iron pipe surface and so prevents oxidation. Hot water systems require more of the chemical than cold systems.—INCO.

8.6, 5.4

**Painting and Maintenance in the Textile Industry.** A. Holden. *Building Topics,* **4,** No. 2, 5-10 (1950); *Text. Wkly.,* 563+ (1950); *Rubber Res. Abs.,* **28,** No. 4, 259 (1950).

Paint in textile mills has to stand up to a moist atmosphere and the corrosive action of chemicals. The use of chlorinated rubber paints for steelwork, machinery and walls is discussed. For painting corrugated iron roofs and similar exterior work, bituminous coatings are recommended. The importance of careful preparation of surfaces prior to applying new coatings is stressed.—RPI.

## • Group VIII

8.8, 4.4

**Melamine—by Calco.** M. M. Hoover. *Chem. Eng.,* **57,** No. 4, 132-134 (1950) Apr.

Because of the highly corrosive nature of dicyammonia mixtures used in the production of melamine for melamine-formaldehyde resins, all autoclaves, pumps, pipes and packaging equipment are stainless steel or stainless-lined. The solvent storage, handling and recovery systems are made of steel.—INCO.

8.8, 1.3

**Problems of Corrosion and Materials of Construction in the Cosmetic Industry.** L. W. Haase. Seifen-Ole-Fette-Wachse, **75,** 334-336, + (1949).

A review.—MA.

8.8, 5.9, 5.4

**Maintenance in Pickling Shops.** G. T. Dunkley. *Prod. Fin.,* **3,** No. 6, 48-52, + (1950) June.

Owing to the humid atmosphere and acid fumes present in pickling shops, conditions there are particularly corrosive. The article recommends the use of acid-resisting brick set in acid-resisting mortar for walls, but other walls and also concrete floors may be protected by chemical resistant coatings. The author suggests that iron and steel-work is best


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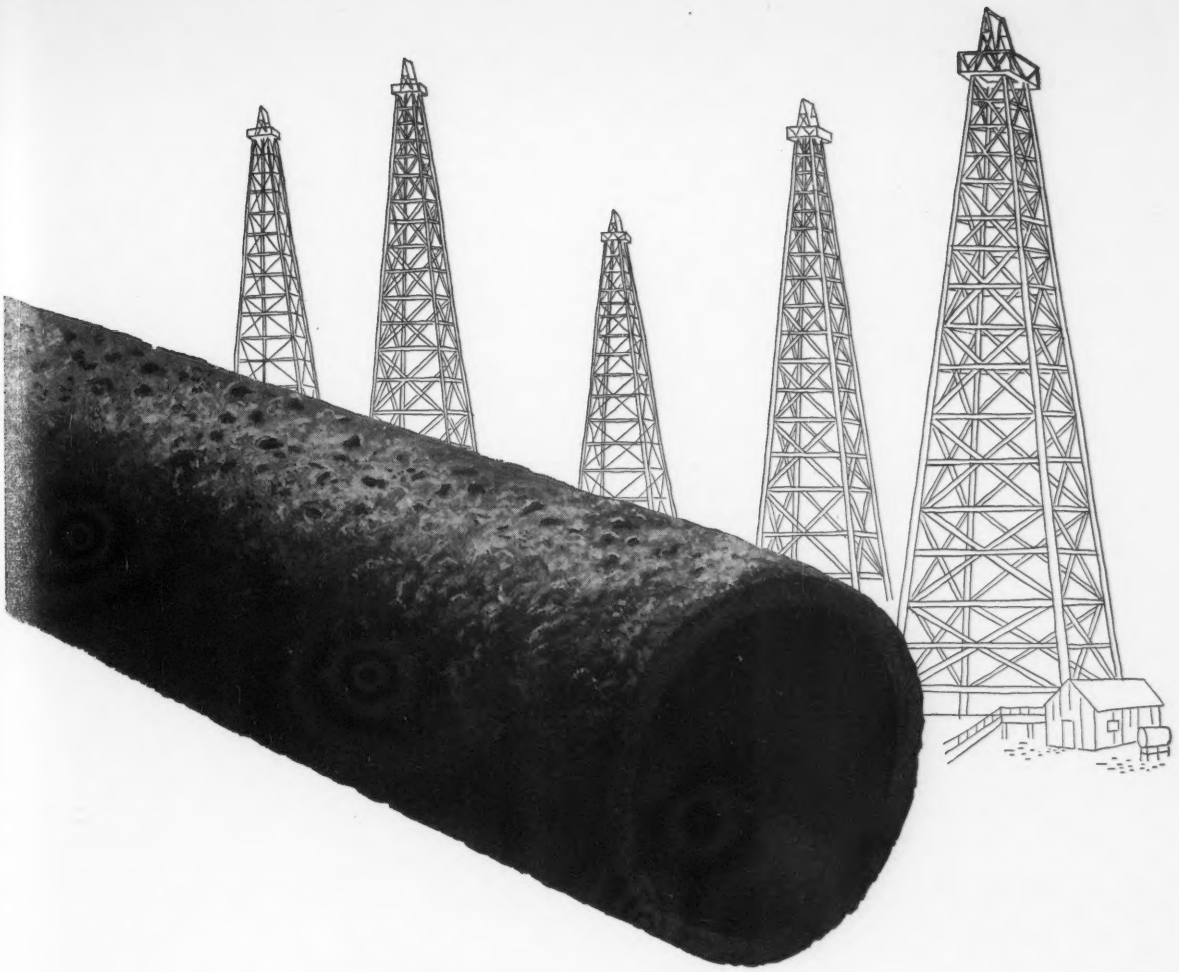

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treated with chlorinated rubber paints, although bituminous paints are also satisfactory. Very careful preparation of the base is necessary before painting and the paint film should be such as to completely exclude the acid fumes from the basis materials.—ZDA.

**8.8, 4.3, 5.10**

**Corrosion Resistant Materials and Coatings in Trail Chemical Operations.** E. A. G. Colls. *Trans. AIMME,* **187,** 491-494 (1950) Apr.

Discusses corrosion in above plants producing ammonia, sulfuric, nitric and phosphoric acids, ammonium phosphates, sulfate and nitrate, together with miscellaneous allied material problems and their solution using erosion or corrosion-proof materials.—BLR.

**8.8, 6.3**

**Lead as a Material of Construction in Chemical Plant.** A. Lloyd. (England.) *Soc. Chem. Ind., Conference on Materials of Construction in the Chemical Industry,* 143-148 (1950) April.

Types of chemical lead; mechanical properties (tensile, fatigue, creep, pressure in pipes); crystalline (grain) structure; welding; homogeneous lead lining; corrosion behavior.—BNF.

**8.8**

**Plant Corrosion in the Fatty Acid Industry.** R. J. Paul. *Corrosion,* **5,** No. 12, 439-442 (1949) Dec.

A brief outline is presented of materials used for equipment, pumps, and piping in the older processing methods, followed by a summary of new material applications. Several non-ferrous metals are mentioned.—MA.

**8.8, 6.2, 6.3, 4.3**

**Corrosion-Resistant Alloy Steels in the Heavy Chemical Industry.** F. H. Keating. *Nickel Bull.* (1949) Dec.; *Intern. Chem. Eng. & Process Ind.,* **31,** No. 4, 176-180 (1950) April.

Small traces of oxygen sustain the corrosion-resistance of chromium-nickel austenitic steel in hydrochloric acid and hydrofluoric acid media. 18-8 stainless steel is an improvement over chromium steel. 18-8 stabilized with titanium or columbium is completely resistant to intercrystalline disintegrations and more resistant to corrosive liquids. 18-8 molybdenum steel is resistant to chlorides, sulfites, and sulfuric acid. Increases in nickel and manganese content promote ferrite stability, but may introduce other difficulties. Other, more highly alloyed steels, as Hastelloy, are mentioned.—INCO.

**8.8, 6.2**

**Corrosive Action of Electrolyte Upon Chromium Plating Installations.** L. Koch. *Metalloberflache,* **4,** No. 5, A65-A68 (1950).

Study of actual cases of damage to steel parts in contact with chromium plating solutions. Nature of damage. Corroborative laboratory experiments. Intensity of attack by a solution of 47 oz/gal. chromic acid and 4.7 oz/gal. sulphuric acid as function of carbon content of steel. Ways suggested by author for safely avoiding attacks on steel by chromium plating baths. (Translation available from Henry Brutcher, Box 157, Pasadena, Calif.)

**8.8**

**Handling Corrosive Fluids.** I. B. N. Reavell. *Fluid Handling,* 17-20 (1949) Dec.

The author stresses the importance in pilot plant investigations of using the same means of handling corrosive fluids as is proposed for the final plant. Means of transportation and storage are reviewed and reference is made to safety rules formulated by the Association of British Chemical Manufacturers.—RPI.

**8.8, 6.2, 4.3**

**Corrosion Resisting Steels.** I. Qualitative Review of Grades for Chemical Industry. II. Sources of Attack and Comparative Resistance. J. A. McWilliam. *Chemical Age,* **61,** 769-771 (1949) Dec. 3; **62,** 15-18 (1950) Jan. 7.

Part II includes tables showing quantitative weight losses of various steels resulting from attack by common acids. —MR.

## • Group IX

**8.9, 5.2**

**Aramco Trans-Arabian Pipe Line.** *Fluid Handling,* **1950,** No. 3, 38-42; No. 4, 91-93, Feb., Mar.

General description of the political and economic-historic background of the pipe line already known as Tapline. Details of the landing of the pipes by the Skyhook are given. Problems set by transporting the pipe sections over the desert, their welding, ditching and protection against corrosion are discussed. Protection of buried sections are discussed. Protection of buried sections of the line is achieved by a field applied coat-and-wrap job supplemented by cathodic protection using Mg anodes. Buried sections of as much as seven miles may be protected by a cluster of no more than two 17 lb. Mg. anodes.—INCO.

**8.9, 7.1, 5.8**

**Prevention of Damage Resulting from Brine Drippings on Track and Structures.** W. E. Cornell and Others. *Area Bull.,* **51,** 661-663 (1950) Feb.

Consists of Report on Assignment five of Report of AREA Committee five on Track. Outlines results of laboratory and track tests in which various inhibitors were added to the brine solutions used in refrigerator cars to minimize corrosion. It was found that sodium hexametaphosphate, and possibly disodium phosphate, give promise as nontoxic inhibitors. Use of other inhibitors poses serious toxicity problems.—BLR.

**8.9, 5.3**

**General Motors Research Developing Aluminum Coated Mufflers.** *Automotive Ind.,* **101,** No. 8, 23 (1949) Oct. 15.

General Motors Research has done considerable experimental work in the development of aluminum-coated steel parts for mufflers. About 10 percent of the Chevrolet replacement mufflers are aluminum coated. Laboratory and service testing indicates these have a life expectancy about three times that of conventional mufflers. The outer shell is made of aluminized steel which is commercially available. The inner parts which require formation and perforation are made by a new aluminum dip process.—ALL.

**8.9, 6.4**

**Navy Studies PT Boats with Aluminum Hulls.** *The Alcoa News,* **21,** No. 7, 1-2 (1950), Apr. 3.

Four PT boats framed and plated with aluminum are being built at East Coast shipyards for the U. S. Navy as part of an experimental program investigating marine uses of aluminum. A motor torpedo boat built in 1939 was decommissioned in 1941, and the enforced period of inactivity during the war permitted the boat to give positive evidence of the durability of an aluminum hull. When reinstated in 1946, the boat was found to be in excellent shape and was put back in service. The weathering characteristics shown by this aluminum hull instigated the production of more aluminum craft for the navy. —ALL.

**8.9, 4.2, 1.7**

**Application of Corrosion-Resisting Materials to Railroad Electrical Construction (A condensation).** H. F. Brown. *Corrosion,* **6,** No. 8, 268-273, (1950), Aug.

Summarizes work of AAR committee on relative corrosion of ferrous and nonferrous alloys in various atmospheres (smoky and clean, sea coast and inland) in order to determine the most economical alloys for use in overhead contact systems of electrified railways. The work has been carried on since 1930. Various test specimens are illustrated. Data are tabulated. Includes work on protective coatings.—BLR.

**8.9, 7.10, 5.3, 6.5**

**Longer-Lasting Materials for Truck and Bus Mufflers.** E. E. Bryant. *SAE J.,* **58,** No. 3, 46-47 (1950), Mar.

The use of coated products such as aluminized steels offers considerably more life than ordinary mild steel of equivalent gauge for truck and bus exhaust systems. A bonded coating of aluminum rolled on to ordinary mild steel is exceptionally resistant to rusting from weather conditions and offers a fair degree of corrosion resistance. It works quite readily in general fabrication but lacks drawing ability or ability "to fold back on itself," as required in some muffler end flanges. Aluminized steel needs no paint because of its coating, and will withstand temperatures as high as 1500°F (816°C). Aluminized steels are being subjected to higher heats in exhaust systems in several test programs now under way. Tests conducted with terne plate (lead-coated steel) and zinc grip are evaluated. The development of hot aluminum dipping after fabrication which calls for more expensive equipment and greater skill than other procedures, is being considered by General Motors Corporation and other fabricators of truck and bus mufflers. Porcelain coated steel and stainless steel used for the same purpose are evaluated. Aluminum mufflers, which would be limited to low-temperature exhaust systems, have been tested in an effort to reduce weight and corrosion. These mufflers failed because the metal fractured, possibly as a result of crystallization. Heavier gauges and internal bracing might eliminate metal fracture, but the cost would then rise. The development of new aluminum alloys may produce an economically competitive material.—ALL.

**8.9, 3.5, 3.7**

**Corrosion in the Stratosphere.** *Ind. Eng. Chem.,* **42,** No. 2, 7A, 10A (1950) Feb.

The various causes of corrosion of air-

planes are discussed and several protective measures are presented.

Galvanic action between dissimilar metals is difficult to control. Magnesium should be insulated from other structural metals, especially from 75 ST aluminum alloy. The electrolytes required for galvanic corrosion are supplied by salt, rain, tapwater, primer extract, and exhaust condensate. The constantly varying environment to which a plane may be exposed promotes galvanic and other types of corrosion.

The occurrence of metal fatigue at joining sections is partially overcome by employing thermosetting resins instead of rivets or welds.

The increased pressures and temperatures that accompany high speed create new problems. Atmospheric gases forced into closer contact with metal surfaces probably change the equilibrium constants of the chemical film already formed under normal conditions and thereby increase the corrosion rate.

At very high altitudes the lower vapor pressure may also affect the composition of the protective film. The low temperature causes moisture from passengers' breath to condense on the inside walls of pressurized cabins, and the high carbon dioxide content promotes acid reactions.

Minor problems include corrosion of structural members by eddy currents induced by higher a-c frequencies and voltages, corrosion of engines by antiknock agents, and corrosion of fuel tanks by the bubble fluid used to test tank tightness.—PDA.

8.9, 6.4, 7.2

**Aluminum Gas Line.** *Mechanical Eng.*, 72, No. 3, 246 (1950) Mar.

An all-welded aluminum gas line will be installed extending underground approximately 1.8 miles from the main trunk line of the Alabama-Tennessee Natural Gas Company to the Listerhill, Alabama, plant of Reynolds Metals Company. The line consists of extruded Alcoa 63S-T6 aluminum alloy pipe with outside diameter of 8⅝ inches and walls ¼-inch thick, which will withstand a working pressure of 200 psi and a bursting pressure of 1750 psi. Forty-foot lengths of pipe will be used, butt-welded with two passes, using 3/16-inch diameter 5 percent silicon-type aluminum rod. The Heliarc method will be used, providing a complete shield of inert gas around the weld zone which protects the weld and surrounding metal from atmospheric corrosion. The length of the line, including joints, will be wrapped after welding by applying cold No-Ox-Id pipe wrap made by the Dearborn Chemical Company. A single 40-foot section will be left unwrapped, by-passed by a wrapped section, and the former will be dug up at six month intervals to determine whether the wrapping of the aluminum pipe is necessary.—ALL.

8.9

**Aircraft Fabrication Revolution?** Alexander McSurely. *Aviation Week*, **52**, 15-16 (1950) April 24.

Outlines new process which squeezes out airplane skin for wings and fuselages complete with built-in stiffeners thus creating a new semifinished material for planes. Ribbed sheet suitable for airplane wings and fuselages is produced from 75S alloy.—BLR.

8.9, 3.6

**Electrolytic Corrosion of Steel in Concrete.** G. M. Magee. Assn. of American Railroads, Washington, D. C. *Corrosion*, **5**, No. 11, 378-382 (1949) Nov.

Two series of field tests were conducted to investigate the corrosion of steel in concrete caused by the use of direct current in electrified railways. When trains are in the vicinity, a potential of perhaps 25 v may exist between the catenary structure and the ground with a resulting current flow and corrosion of the anchor bolts. The expansion from the increased volume of the rust causes cracks to develop in the concrete and permits water to come in contact with the steel, further accelerating the deterioration.

It was found that the deterioration can best be prevented by surrounding the concrete with asphalt membrane waterproofing to insulate it from the ground or by coating the steel with asphalt to insulate it from the concrete. Details of the test are given.—PDA.

8.9, 5.4, 7.2

**Concrete Coated Pipe Used for Swamps and Rivers.** D. J. Kerr. *Petro. Eng.*, **22**, No. 9, D19-22 (1950) Aug.

The H. C. Price Co., Bartlesville, Okla., has developed a process for coating thin walled pipe with a thick layer of concrete to protect it against corrosion and give negative buoyancy. Application of the coating and operations in laying the pipe line are described and illustrated with pictures. The process is called Hevicote.

8.9, 4.4

**Some Case Histories of Shipboard Lubricating Problems During World War II.** W. D. Leggett, G. L. Neely, and J. B. Ritch (U.S.N.). *Trans. Soc. of Naval Architecture & Marine Eng.*, **57**, 352-378 (1949).

Instances of machinery troubles on naval vessels that were lubrication failures are discussed. Some of the difficulties arose from the use of the wrong lubricant or its improper application, some were improper bearing design or problems of metallurgy, and a few show some limiting quality of the lubricant was not fully evaluated in the design of the unit. Submarine shafts had bronze sleeves and sea water was used as lubricant to minimize shaft squeal. The sleeve and the edges of the wood, rubber or plastic strip bearings with the water formed a thick lubricating film. Connecting-rod bearings failed because the loads transmitted through the oil film were greater than the fatigue strength of the bearing metals. A steel back overlaid with bronze or copper-lead which was overlaid with a low-friction bearing material gave protection to the crankshaft in case of failure and support to the bearing when operating normally. Gun elevating screws are alloy steel shafts with square-cut threads. The oscillating nuts have bronze internal threads. With mineral oils as lubricants there was a bronzing of the steel. Use of heavier gear oils, OS 1400, eliminate this problem. Photographs. 6 Ref.—INCO.

## • Group X

8.10

**Surface Corrosion in Coal-Washing Plants in Holland.** H. G. Zelders. (In French.) *Metaux et Corrosion*, **24**, No. 283, 65-76 (1949) Mar.—BNF.

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8.10, 6.1, 3.7, 5.3, 5.4

**Corrosion of Iron and Its Prevention in Mine Shafts.** Franz Eisenstecken. (In German.) *Stahl und Eisen*, **68**, 164 (1948) Apr. 22.

Summarizes results of an investigation covering ten different types of steel and four of cast iron and the protecting effect of alloying elements and of coatings.—BLR.

8.10, 1.6, 6.2

**The Ferrous Metal Industry in Germany During the Period 1939-1945.** George Patchin and Ernest Brewin. 270 pages. His Majesty's Stationery Office, London. BIOS Overall Report No. 15. (T26 G79ov.) (1949).

Describes blast furnace plants and practices, steel production, working, foundry practice, heat treatment, machining, finishing, testing, and research. Considers steels, ferralloys, and hard metals.—BLR.

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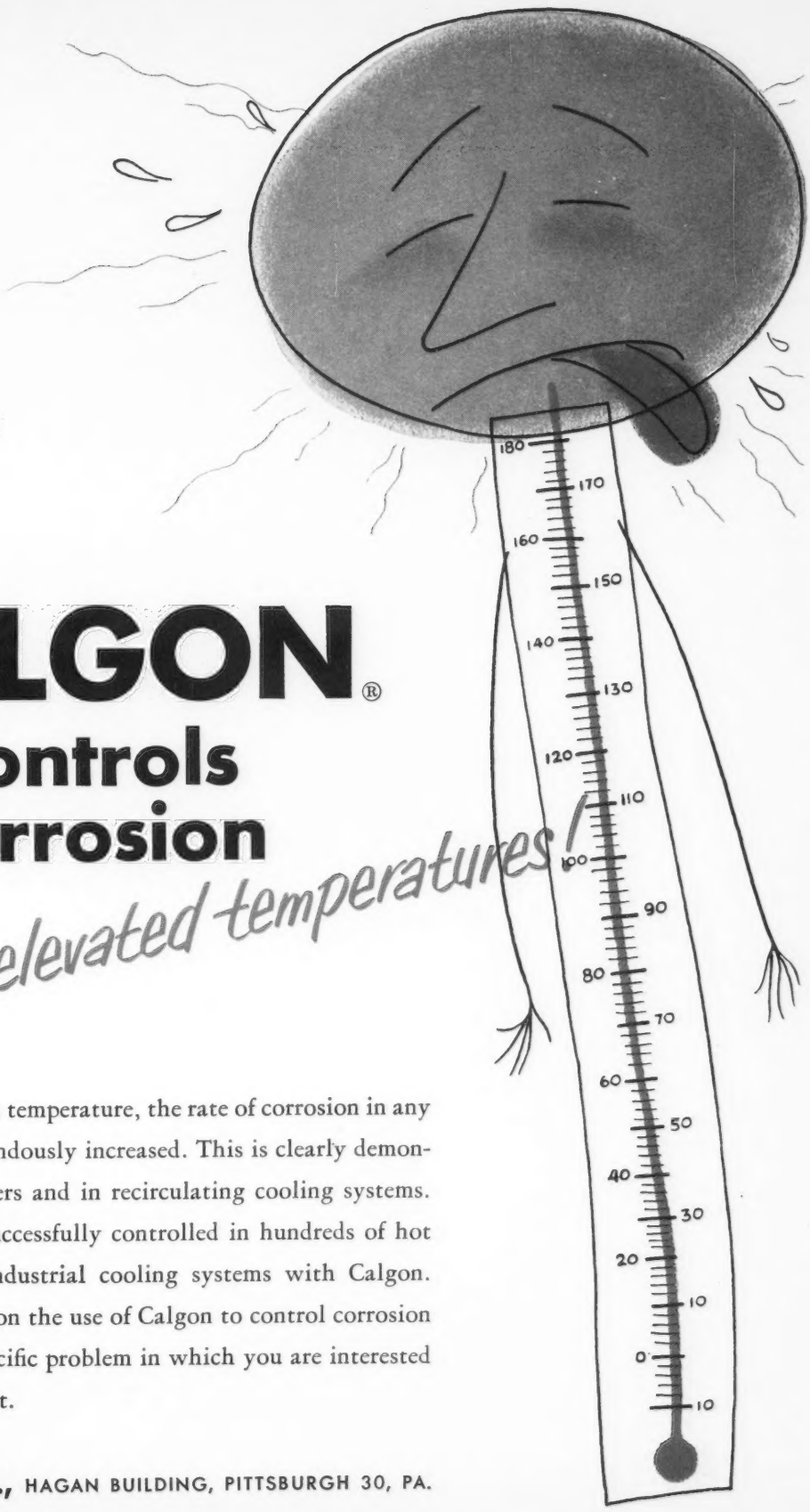


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